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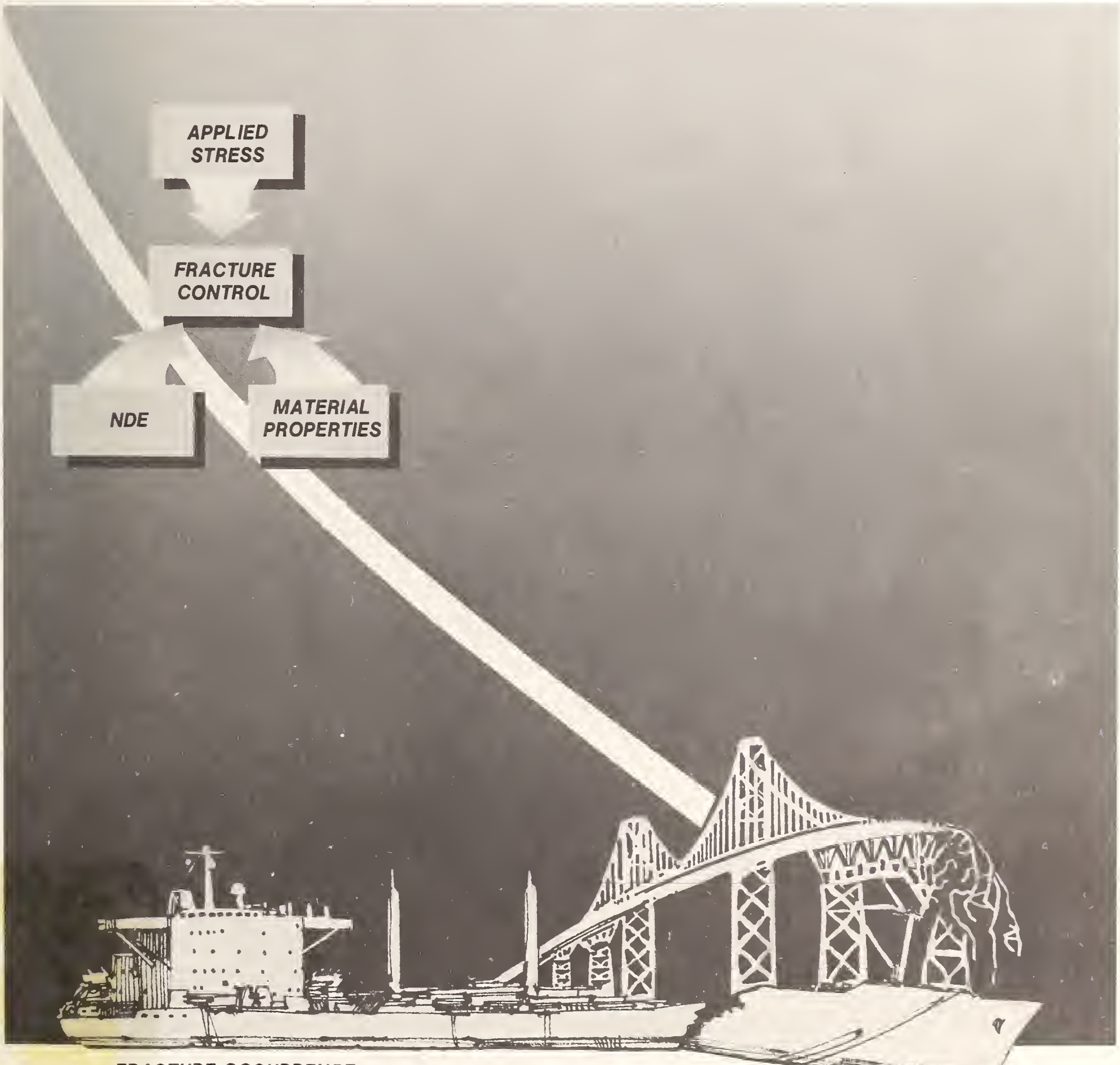
The Economic Effects of Fracture in the United States



FRACTURE PREVENTION

FRACTURE OCCURRENCE

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The Economic Effects of Fracture in the United States

Part 2 — A Report to NBS by Battelle Columbus Laboratories

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A.R. Rosenfield, A.R. Buhr, E.J. Honton,
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FOREWORD

This study on the Economic Effects of Fracture in the United States is the second program of this general type undertaken by the Battelle Columbus Division on behalf of the National Bureau of Standards. As in the earlier study on corrosion, the analysis was based on an Input/Output model of the U.S. economy, and required detailed study and alteration of the factors which describe all interindustry transactions.

No effort of this complexity could be performed in a vacuum. From the initial definitions of scope and approach to the intensive examination of the 150-sector model, many researchers have contributed insights, information, and inspiration. No list of associates could do full justice to their total contributions.

Several, however, deserve special mention. Among the principal Battelle researchers, Frank Holden and Allen Hopper supplied both general and specific insights which were invaluable in all phases of the program. Patrick Stephan, Donald Hill, and Deborah Carter--our three principal data-collectors --brought to the project the technical expertise necessary to provide base-line data on which an advanced analytical tool could be developed. Numerous other Battelle staff were most helpful in supplying data specific to a broad number of industries and their practices. Professor Andrew Brody, a Battelle Distinguished Visiting Scholar and authority on I/O modeling, added an essential understanding to the critical issues of reliability and sensitivity.

The authors also appreciate the support and consideration given at all levels of Battelle management. Their continued interest, understanding, guidance and assistance have been most welcome throughout the program.

A very special note of thanks is due to Harry Barr, whose broad knowledge of almost every industrial sector and his sensitivity to the demands of the I/O approach represent a unique talent.

An Advisory Board, drawn from a wide spectrum of interests, provided commentary and guidance which has served to place this work in a more realistic context, assuring that the approach and results served a broad audience. These Advisory Board members included:

Dr. Anne P. Carter
Brandeis University

Mr. Lawrence Casellini
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Mr. Joseph Cirillo
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General Dynamics Corp. (Ret.)

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National Materials Advisory Board (Ret.)

Mr. Foster Wilson
Owens Corning Fiberglas Corp.

At all stages of the program, it has been apparent that this has been a cooperative effort with the National Bureau of Standards. The project has clearly been carried out with, rather than merely for, NBS. Drs. Richard Reed, John McKinley, Elio Passaglia, John Smith, Bruce Christ, and John Wachtman have each made their impacts on the program; they have guided, they have shared their perspectives and concerns, and they have shed considerable light on the utility of the work. And finally, Dr. Edward Berman, consultant to NBS, has--through his challenges, interest, and enthusiasm--helped make this study more germane to the benefits of all parties.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF APPENDICES

TABLE OF CONTENTS (Continued)

LIST OF APPENDICES (Continued)

TABLE OF CONTENTS (Continued)

Page

LIST OF APPENDICES (Continued)

LIST OF TABLES

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

THE ECONOMIC EFFECTS OF FRACTURE IN THE UNITED STATES

by

J. J. Duga, W. H. Fisher, R. W. Buxbaum,
A. R. Rosenfield, A. R. Buhr,
E. J. Honton, and S. C. McMillan

SUMMARY

Materials produced in the United States--and the structures, containers and other products made from them--are all subject to fracture. For this reason resources have been directed toward many aspects of the attainment of structural integrity. Substantial effort is continuously directed toward: improved understanding of fracture mechanics; development of more fracture- and fatigue-resistant materials; improved processing techniques to achieve more uniform materials; utilization of design concepts to reduce the potential for structural failure; advancement of nondestructive evaluation equipment for both inspection and preventive maintenance; and development of consumer educational materials, maintenance guides, and operating instructions to ensure the proper use of products.

While our understanding of material fracture has advanced considerably over the past several decades, we still need to overdesign structures so as to maintain safety factors and to assure reliability, and we still expend much effort on maintenance and repair to prevent catastrophic failures. These and other activities represent uses of resources (materials, energy, labor, devices, etc.) that could be diverted to other worthwhile purposes were it not for the simple fact that things break.

In spite of our efforts to prevent or to anticipate fracture, breakages do occur--often with tragic consequences. The injuries and losses of life resulting from the recent Kansas City Hyatt Hotel walkway collapse, the fall of the Silver Bridge in Ohio, and other similar events remind us that the results of fracture-related incidents can be devastating.

The present study was undertaken with the objective of estimating several different costs or levels of resource utilization:

- <u>What is the total cost of fracture in the U.S. economy</u>? It is estimated that the resources consumed in anticipation of, or as a result of, fracture amount to <u>$99.0 billion</u> annually (in 1978 dollars).

- <u>How much of these costs could be reduced by the application of presently known technology</u>? Approximately <u>$29.1 billion</u> could be saved if all known best fracture control practices were applied throughout the productive economy.

- How much of these costs could be reduced by further research into fracture-related technologies? It is estimated that future research could reduce these annual costs to the economy by an additional $23.4 billion.

This project was undertaken with an appreciation of the fact that total costs cannot be determined by the simple summing of all the expenditures devoted to the individual components of fracture-prevention activities, or a summing of those costs which accrue as a result of fracture-related events. Such an approach would, at best, provide a microeconomic accounting that neglects the complex interactions among the many diverse sectors of the economy. Based on the experience with an earlier study for the National Bureau of Standards ("The Cost of Corrosion"), Battelle again employed a full Input/Output (I/O) model, thus permitting an examination of the direct and indirect resource flows which result from consideration of material fracture.

While most of the costs of fracture could be accommodated easily within the I/O framework, the objective of isolating those other costs associated with accidents and similar "visible" events required the development of a set of specialized Supplemental Models. These latter were applied to a broad range of accident types, and served as the basis for determining both resource and imputed costs attributable to fracture-related events.

Battelle's I/O model is technology based, reflecting all activities which derive from the actual technologies of production. Thus, any technological factors which affect industry can be incorporated as changes in the model, and their impacts can be traced throughout the economy. The general application of this tool requires both detailed knowledge and judgment on the part of experts familiar with all manner of industrial processes. In view of the complexity of the I/O model as adapted to this study (covering 150 different sectors of the economy), and in view of the pervasiveness of fracture-related concerns, Battelle's standard approach to I/O analysis was augmented by the development of generalized rules, which could be applied across a majority of sectors. This modification and expansion of the method is expected to permit a more effective use of I/O in assessing the impacts of a wide range of emerging technologies, the consequences of widespread improvements in existing technologies, or the costs of degradation effects (similar to corrosion or fracture).

The estimation of the cost of fracture was undertaken by the definition of four "Worlds", or states of the economy, three of which are directly comparable with those defined in the earlier corrosion study. World I represents the U.S. economy as it actually existed (in 1978), adjusted to conditions of peacetime full employment. World II is a hypothetical construct which describes what the economy would look like were there no unintended fracture and no need to expend resources on fracture prevention. World III is another hypothetical description of the economy, assuming those conditions where all sectors performed according to the known best fracture-control technologies (regardless of where each technology originated).

An additional objective of this study was to estimate the impacts of future research. This World IV--the only part of the study in which a simple summation was employed in place of a full I/O model--represents the potential reductions in costs that could be realized through the conduct of research and the applications of the findings therefrom.

It is important to note that of the total costs of fracture given above, approximately 29 percent could be reduced through the widespread use of presently available technology, that is, through education and technology transfer. An additional 24 percent may be reducible through research and development in four broad areas: (1) understanding basic materials properties and the mechanisms of material failure; (2) improving our knowledge and application of processing techniques; (3) specialized fracture-prevention design and related computational efficiency and accuracy; and (4) "support" areas related to inspection, testing, maintenance, and reliability control.

The total cost of fracture ($99.0 billion) is 4.4 percent of the Gross National Product for "full employment" 1978. If we assume no great change in the relative size of these costs in today's economy--with a GNP of approximately $3,000 billion--current (1982) costs of fracture are running at a level of about $132 billion per year.

Two major factors deserve special attention at this point: (1) the magnitude of the costs associated with accident-related events; and (2) the basically conservative nature of the I/O model. The total resource and imputed costs which result from accidents and other similar events amount to slightly less than $2 billion. This is considerably smaller than the $34 billion estimated by the National Safety Council as being the cost of automobile accidents alone in 1978. However, it must be emphasized that the total events cost defined here account only for those events which are caused by fracture; even within that limiting definition, we exclude from the scope any fractures that are the result of acts of violence or vandalism, operations beyond design, natural disasters of magnitude greater than that expected in original design; and similar causes. We have included only those events which could be associated with the types of causes that conceivably can be addressed through efforts of those organizations that are concerned directly or indirectly with fracture technology.

This estimate of event-related costs is subject to errors associated with the paucity of reliable data on the true causes of events. However, the analysis was carried out so that this portion of the costs is considered to be a maximum. That is, fracture-related events, within the scope of this study, could be as high as $2 billion annually.

With regard to the I/O model outputs, the estimates provided in this study are on the conservative side; that is, the original estimates were subject to a 26 percent confidence range. The dollar figures cited above therefore have already been subject to a 13 percent adjustment for underestimation. Even so, these resource costs can still, with reasonable assurance, be interpreted as lower bounds--the present cost of fracture is at least $99 billion annually. Similarly, the estimates given for the (present or future) reducible costs are also conservative.

It is shown that while the general order of magnitude of the costs of fracture is essentially the same as that which had been estimated for the costs of corrosion, there is a significant difference in the makeup of these costs. Broadly speaking, in each study, the costs fall into two broad classes: those associated with changes in technology and those associated with changes in demand. In the case of corrosion, over 70 percent of the cost of corrosion arose from changes in demand, much of which could be directly tied to the effect of corrosion on automobiles. In the fracture study, over 80 percent of the costs are technology based. They derive primarily from technologies of production and the amounts of material that are used in production processs in order to prevent fracture. It is largely within this area that future research and development will have their greatest impacts.

It is shown that future cost reductions can be addressed on a sector-by-sector basis through a detailed analysis of the cost components that accrue to individual sectors and are provided in this report. A major portion of resource savings may be realized by the transfer of existing technology, i.e., applying a tchnology developed for one use to another one, perhaps far removed. Depending upon the particular sector(s) involved, savings may accrue to producers, to users, and/or to society at large.

In addition, an almost equal resource savings may be obtained through basic and applied research, and the subsequent dissemination and application of new technology throughout the productive economy.

Regardless of whether future efforts are directed toward applications of existing technology or toward advancements of technology, the target for future savings is highly significant.

I. INTRODUCTION AND OVERVIEW

The prevention of material fractures consumes major resources in the total economic flow of the United States. Such resources, including materials, manpower and energy, are expended both directly and indirectly in an effort to prevent the fracture of structures and containers; to assure the physical integrity of consumer goods and the safety of equipment; and to develop and apply maintenance and inspection procedures for the prevention or identification of critical flaws. In addition, capital resources are expended in the stockpiling of inventories or redundant equipment which are held in anticipation of fracture. Replacement parts or entire units are held in reserve--freezing capital which might be used for other purposes--for little reason other than to ensure the continued performance of an activity or function in the event of a component failure.

Starting with the premise that, under a variety of conditions, materials will fracture or otherwise be physically altered so as to preclude their application in a particular configuration, one is led to the conclusion that material fracture considerations have a far-reaching and pervasive effect on the U.S. economy.

In addition to the fact that fracture prevention (through materials selection, design, and inspection) represents a major resource flow, there are the additional costs that accrue as a consequence of unintended fracture. One need only look at a few of the more spectacular fracture-related accidents to obtain an appreciation of those consequences:

- the fracture of airplane components, resulting in disastrous accidents similar to the well-known DC-10 crash in Chicago
- the fracture of support members leading to the collapse of the Silver Bridge in Ohio, with subsequent deaths and injuries
- the fracture of railroad wheels or tracks, leading to derailment, the consequent rupture of tank cars, and the spillage of hazardous, toxic, or other environmentally degrading chemicals
- the recent collapse of overhead walkways in the Kansas City Hyatt Hotel.

These consequences of fracture include not only the personal human costs in pain, suffering, and death, but also those costs that are reflected in losses of cargo, business costs of delay, environmental damage, and the costs of environmental cleanup.

The total impact of fracture on the U.S. economy is a measure of both the resources expended in fracture prevention and those costs and other resource flows incurred as fracture consequences. The economy, having developed into a complex system for the delivery of goods and services, is highly dependent upon a number of different factors. Advances in technology--in terms of both basic and applied sciences--have had a significant role in shaping that economy. Research in electronics has changed the way in which we communicate, the manner in which we conduct business, and the forms of entertainment that we enjoy. Research in transportation has affected our personal mobility, the delivery of essential material for consumer and industrial use, and the distribution of fuel supplies. And research in basic materials, engineering, and construction techniques have impacted the appearance of our cities, the tapping of resources, and the development of an enormous spectrum of consumer goods. Inasmuch as past research has markedly affected the overall economy of the U.S., it is reasonable to assume that future research will have a similar result.

Can one expect, for example, that advances in fracture-related research could result in the delivery of the same goods and services at a lesser expenditure of resources?

Would new developments in materials, design, construction, and maintenance permit a decrease in the costs or distribution of fracture prevention expense without a concomitant increase in the costs associated with fracture occurrence?

Can advances in fracture technology result in a change in overall resource flows such that the savings in materials, manpower, energy and capital could be diverted to other more productive activities?

In order to begin the process of addressing such questions, it is instructive to review briefly some of the advances that have significantly affected the prevention of fracture.

Historical Progress in Fracture Prevention

The history of efforts to avoid structural failure is long and fascinating, replete with spectacular bridge collapses, tank explosions, and other disasters. The many structures that have survived over the centuries attest to the successes of the early designers and builders. Much of that success was based upon trial and error designs and highly redundant uses of materials. Most of today's technology in analysis, design, materials, and construction has evolved over the past two centuries, although many of the key elements were known (or at least observed) and frequently practiced long before that.

Improvements in Materials

With the exception of polymers, the common materials of construction have been used in one form or another for centuries: wood, stone, metals and alloys, glass, and ceramic materials. However, the industrial revolution of the 1800s marked a period of significantly rapid development both in the methods of producing materials and in their application. It was not until the 20th Century that an understanding was developed of how the composition and microstructure of materials determine their properties, leading to the degree of control in the production of materials that we have today. This century also has seen the development of polymers from laboratory curiosities to a class of materials competitive with wood, metals, and ceramics.

Materials today are produced to industrial standards of composition and microstructure that represent a balance between product quality and cost. Those standards commonly differ according to the material and its intended use; aircraft quality steels, for example, are produced to tighter specifications than structural steels and are therefore more costly.

Improvements in Design

Engineering design as we know it today is largely based upon the principles of mechanics and the theory of elasticity. Although the foundations of those disciplines can be traced farther back into history, the most significant developments took place during the 19th Century. Further refinements were made during the first half of the 20th Century, and these gradually made their way into industrial design during that period. Modern analysis and design methods have evolved during the last twenty years or so, following the introduction and rapid use of electronic computing equipment. This technology continues to progress rapidly as further computer-assisted design methods are realized.

Improvements in Testing/Inspection

The testing and inspection of materials (as distinguished from products) has evolved mainly during this century. Before that time there was little testing of materials properties, and inspection rarely went beyond visual examinations. With the introduction of rational design methods, it became necessary to characterize the mechanical properties of materials, and equipment for that purpose was developed in the late 1800s. Testing machines have been continually refined and increasingly automated during the past decade to include sophisticated computer control and data reduction systems. The impact test was increasingly utilized during World War II and the years immediately following, as the problems of brittle fracture of ordnance components and cargo ships received attention.

Inspection procedures likewise received increasing attention during World War II with such techniques as radiography and magnetic particle analysis. Inspection techniques for the detection of flaws has continued since that time with the development of acoustic emission, eddy current, and ultrasonic systems, many of which are still being refined.

Developments in Fracture Mechanics

The study of fracture as a phenomenon dates back to about World War I and the subsequent theories relating the strength of brittle materials to the presence of microscopic flaws. Here again, the problems encountered during

World War II with brittle fracture of steels, as well as such postwar problems as the British Comet jet airplane and high-strength steel rocket motor cases, provided impetus to the development of fracture mechanics.

This discipline is the unifying factor in mechanical failure prevention since it contains the major components of safe operation. It is now recognized that the strength of a flawed material may be significantly lower than that of a perfect material. This finding is embodied in the material fracture toughness property. Design and overload protection can proceed based on a knowledge of toughness, so that the failure load of the body is not exceeded. Testing insures that the material has sufficient toughness and load-bearing capacity for its function. Inspection detects the presence of critical flaws and maintenance insures that, once detected, they are eliminated. Certain industries are now using fracture mechanics as a design method--aerospace and nuclear vessels, for example--and current research is active in this field to extend its applicability to more materials classes and systems.

The Pervasiveness of Costs

The total resource costs which accrue in the attempt to preclude fracture, as well as those costs associated with the consequences of fracture, cannot be totally determined or appreciated by the simple expedient of tallying individual direct dollar values. It would be tempting, for example, to make simple assumptions regarding direct outlays for material and manpower which would account for the added sales of reinforcing bars or the salaries of inspectors. Or to compute that portion of direct materials and labor costs which account for repair of bridges and highways. Or to total the direct medical or cargo loss costs associated with accidents related to transportation or falls from defective scaffolding.

To be sure, these are typical of the kinds of costs which are attributable to fracture. However, such an exercise would severely underestimate the total impact of fracture on the U.S. economy. Furthermore, it would preclude any detailed and cohesive effort to identify those types of research or other activities which might be undertaken to reduce the total costs to the economy. The underestimation would result from two origins. First, it is doubtful whether complete coverage of all manner of individual cases or events could be compiled and properly attributed to materials fracture.* Second, the mere summation of direct costs does not permit an accounting of those indirect and downstream costs which are fracture-relevant. For example, the cost of fracture surely includes the direct cost of maintenance, including the materials consumed during that process. In the simple case of pot-hole repair, one should consider not only the material used for filling voids, but also the raw materials and energy consumed in preparing basic patching compounds; the cost associated with transport of such raw and finished materials; the capital

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* As will be seen later, the compilation and attribution in only one subset of fracture-event information is a major undertaking which is compounded by a lack of detailed historic investigative data.

equipment required to mine and process the original resources; and the list goes on and on.

The determination of total costs to the economy requires a much more sophisticted approach coupled with a consistent method of collecting the appropriate data. As will be shown in the following sections and chapters, the application of a detailed Input/Output model of the U.S. economy permits a tracking of all fracture-related costs, and an attribution of these costs as they are encountered throughout the economy.

Program Objectives

The statement of program objectives rests principally on two factors that have been discussed above:

(1) the fact that materials can fail has a profound effect on the total U.S. economy, in terms of both the resources used to prevent failure and the costs that accrue as a result of failure*; and

(2) the need to determine the extent to which present and future reducible costs of failure can be addressed through the broader application of known technology and the development of better technology.

In order to accomplish the objectives noted below, an economic modeling approach was adopted that would lead to an estimate of three basic measures:

(1) the total economic activity in the U.S. under the actual operating conditions of a base year (1978), corrected in such manner as to assume a peacetime, full-employment economy; this description of the economy is referred to as World I, The Real World;

(2) the total economic activity as it would be described in a situation in which undesired materials fracture did not occur; this description is referred to as World II, The No-Fracture World; and

(3) the total economic activity as it would be described under those conditions in which best known fracture control practices were employed throughout all productive processes; this description is referred to as World III, The Best Practices World.

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* In keeping with the convention adopted throughout the course of this program, we shall use the generic term "failure" or the convenient term "fracture" to include fracture and excessive deformation. Unless otherwise specified, these terms will be used interchangably.

It follows from these definitions that the differences between these Worlds provide estimates of three different costs of fracture.

World I - World II represents the difference in total economic activity between the Real World and the No-Fracture World or, in other terms, the total cost of fracture.

World I - World III represents the difference in economic activity between that which actually occurs and that which would occur if the best present technical fracture prevention and control practices were employed in all productive processes. Thus, this difference reflects presently reducible costs of fracture.

World III - World II thus represents the remaining costs, that is, presently irreducible costs of fracture.

It is clear from these definitions that the existance of a positive World I - World III difference suggests that there are available fracture-related practices and procedures which, if applied throughout the economy, could lead to a reduction in the use of selected resources. The attainment of World III may be achieved through the application of that which is presently known; in part, World III may be approached through adaptation or adoption of technologies developed for one purpose and applied to another.

The existance of a World III - World II difference implies that even if all presently known technologies were applied, there still would remain a cost of fracture. It follows that reduction in that remainder can only be achieved through future research; and even then, the ultimate reduction in fracture costs will be limited.

From the definitions of Worlds II and III, it is seen that the productive economic activity under No-Fracture and Best Practices conditions can be carried out with fewer resources. As a result, the resources that would have been used in World I--the so-called "Social Savings" (see Appendix B)--can be channeled into still more productive economic activity.

Just as past research efforts have resulted in refined uses of materials, designs, and practices, future research may be expected to have an impact on the presently determined World III - World II difference. In keeping with the definitions already established, we may now introduce the concept of World IV, the so-called Future Best Practices World.* It describes the economy to which we may aspire, where future fracture-relevant research and its application have achieved their full potential.

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* As will be shown in greater detail in later portions of the report, World IV is not to be described in the same sense as Worlds I, II and III. That is, Worlds I-III are determined by a full Input/Output (I/O) analysis, while the nature of the model and the definition of World IV preclude such detail. We shall continue to refer to this state as World IV in order to preserve consistency.

Given this background, the objectives of this research program are five-fold:

(1) to estimate the total cost of fracture in the U.S. economy;

(2) to estimate that portion of present (i.e., 1978) costs which may be reduced through the widespread application of presently known fracture-relevant technology;

(3) to estimate those remaining costs, i.e., those not preventable through the application of presently-known best practices;

(4) to define those areas of research which, if carried to their ultimate conclusion and applied throughout the productive economy, would further reduce the costs of fracture; and

(5) to estimate the extent to which such research would reduce the cost of fracture.

Structure of the Report

The remainder of this report is divided into chapters and supporting appendices which develop and describe the method, present the results, and discuss conclusions and recommendations.

Chapter II is devoted to a more detailed explanation of the Worlds and their physical significance, and to a comparison between the present "Cost of Fracture" program and its predecessor, "The Cost of Corrosion". This comparison and the "World" definitions are critical in delineating the Scope of this program.

In Chapter III, the general approach is presented, with emphasis on the Input/Output method and the development of Supplemental Models used to describe the impact of fracture-related events.

The specific approaches to both the Input/Output and Supplemental Models are presented in Chapters IV and V, respectively.

Chapter VI focuses on the results of the project, with emphasis on the character of Worlds II and III, and on the differences among all pairs of Worlds I, II, and III. Of particular importance are the World III - World II differences which set the stage for the consideration of future research thrusts and their potential impacts.

In Chapter VII, emphasis is placed on those research areas which are deemed to have the greatest promise in terms of their impact on future reducible costs of fracture.

Following the overall analysis as given in Chapter VIII, final recommendations and conclusions are summarized in Chapter IX.

In order to avoid repetition or extensive footnotes, the reader is referred to a Glossary of Terms (Appendix A) for a summary of those definitions.

Additional appendices have been devoted to presentation of the details of sub-portions and background materials which, while most germane to the project, are deferred so as to maintain the basic continuity of the report. Appendices B - H thus provide:

(B) Definition of the sectors of the I/O model

(C) Details of the I/O approach to economic impact analysis

(D) Details of the so-called "Row-Rules", an approach to ex ante modeling developed for this study

(E) Detailed background on the Supplemental Models developed to account for fracture-relevant costs associated with a variety of fracture-caused events

(F) A summary of the Injury Cost Model prepared under subcontract with Technology + Economics, Inc. (T+E)

(G) A critique on the evaluation of loss of life, used to support findings of the Supplemental Models prepared by T+E

(H) Separately bound detailed computer printouts containing all pertinent data for the materials used in the description of Worlds I, II and III, and the differences among them.

II. THE SCOPE OF THE PROGRAM

The "Cost of Fracture" program utilizes an approach and set of itions which are somewhat difficult to understand and which may appear at nce with common experience. Perhaps no concepts are more alien than two related factors which must be established at the outset and which will e the range of applicability of the results. First, there is the concept no-fracture World (World II), a situation in which no unintended, non-icial fracture occurs. And second, there is the question of "Scope", ding a determination of those situations which fall into or out of deration in this program. It will be seen throughout the report that definitions and their applications relate intimately to the approach is taken for the Input/Output (I/O) portion of the program, to the tion or exclusion of fracture-related events (in the Supplemental s), and to the types of future research which are suggested.

It will also be seen that many fracture-related events, including which are very dramatic and visible, may actually fall outside the scope e study and its attendant definitions. With one of the major objectives the development of insights relative to future fracture-relevant rch, it will be seen that almost all events which are excluded from Scope hose same types of events which may not be prevented by research on ure.

Comparison With the "Cost of Corrosion"

The present study of the "Cost of Fracture" is the second program of type to be undertaken by Battelle for the National Bureau of Standards. the earlier study on the "Cost of Corrosion", Battelle's basic method zes the I/O Model. In spite of the similarity in approach, however, are significant differences between these two projects. As a result, derable care must be exercised in comparing the two studies and their ctive outputs. It will be seen from the program differences noted below a direct comparison is beyond the purview of the present report and d, in fact, be treated as an entirely separate activity.

Some of the most important distinctions between the studies are:

(1) The corrosion study was restricted to metallic corrosion, whereas the fracture study is expanded to consider metals, ceramics and glass, polymers, wood, and composites.

(2) The corrosion study defined a hypothetical world in which no adverse corrosion occurred and no precautions had to be taken to prevent corrosion. The analog in the fracture study--the world without fracture--cannot be quite so absolute, for such a construct could lead to completely unrealistic results. The "world without fracture" does, in fact, permit fractures (for example, under conditions of usage outside of design).

(3) Both the corrosion and fracture studies consider the costs of prevention and the consequences as reflected in terms of changes in demands. The fracture study goes further in that it includes an accounting of additional impacts, including those direct and imputed costs associated with human injury, environmental damage, and the like.

(4) The corrosion study was confined to the estimation of presently reducible costs and presently irreducible costs of corrosion. In the fracture study, the latter classification is further subdivided into future reducible and future irreducible costs.

(5) Battelle's basic 126-sector I/O model was redefined to a 139-sector model for the corrosion study, and has been disaggregated to a 150-sector model for the fracture project. This disaggregation has been required in order that special fracture-relevant sectors could be studied individually. In only 85 cases are the sectors common to the two studies.

(6) The calculations for the corrosion study were based upon a model of the full employment U.S. economy for the year 1975; the fracture study is based upon the full employment U.S. economy for the year 1978. Furthermore, the costs associated with fracture events (to be detailed in Chapter VI and Appendices E, F and G) were usually based on averages over a three to five year span, rather than only those events occurring in 1978.

As a consequence of these distinctions between them, it must be acknowledged that the results of the two studies are not completely and simply additive, nor can they be compared directly with each other. This lack of direct comparability immediately brings into focus a potentially serious accounting problem, namely, the possibility of "double counting" between the two studies. In cases where either corrosion or fracture or both are responsible for early failure, conceptually the same failures may be attributed to both. This is especially likely in considerations relative to capital equipment, where replacement rates are affected by increases in useful life. For instance, if the useful life range for a given item is 5-20 years in World I, the lower limit is generally viewed as most susceptible to change in shifting to World II. Therefore, if the range becomes 10-20 years in a no-corrosion world and 11-20 years in a no-fracture world, the reduction of the span by years 5-9 may be viewed as leading to double counting.*

There are some situations in which double counting conceivably is realistic and desirable. For instance, where shorter life spans are caused by a combination of corrosion and fracture--i.e., if either were absent, the span would be longer--double counting is correct. On the other hand, if either

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* As will be noted in later discussion, there are few fracture-related impacts on the capital structure of industry; under normal within-design usage, there is a much greater likelihood that corrosion is the principal determinant of useful lives, and double-counting is not expected to be of significant proportion.

corrosion or fracture could lead to a shorter useful life without the presence of the other, then the double counting is incorrect and should be eliminated.

In keeping with the intent of the National Bureau of Standards' objectives, the present study will concentrate strictly on the fracture-related aspects of the problem. The corrosion study was conducted as if corrosion were the sole relevant cause of failure; therefore the fracture study will be conducted as if fracture/deformation were the sole cause of failure. If it is to be dealt with at all, this question of double counting should be the subject of a subsequent exercise.

The Concept of Worlds

Although the general concept of Worlds was introduced in Chapter I, a more detailed description is necessary in order to gain further insight into the interpretation and utilization of the study's results.

In parallel with the "Cost of Corrosion" study, we first define three "Worlds" that can be used to form the basis of a determination of the costs of fracture. With reference to Figure 1, "World I" represents the real U.S. economy of 1978. As it applies to fracture, the real world is precisely what it implies -- real in the sense that it does in fact describe all the inter-industry transactions which did occur: shapes were fabricated and put into inventory or use, structures broke and were replaced, all manner of services were provided between and among the different sectors of the economy.

"World II" describes a hypothetical world in which, for the most part, all the same interindustry transactions occurred with one major exception: in World II there are no unintended fractures. Material properties are uniform and perfectly known, design and fabrication of all finished structures can be accomplished with perfect knowledge of the stresses and strains encountered in normal use, fully elastic behavior is uniformly observed, no time-dependent fracture processes apply, fracture-relevant inspection of structural members is not required, and the useful lives of all products are not limited by their propensities to fracture or to deform inelastically. In short, World II is a world without fracture within design, and the differences in economic activity between World I and World II represent the total cost of fracture.

In defining "World III", a presumption is made that not all knowledge, materials, designs, and practices are employed in the best possible way; that is, present best practices are not fully and uniformly applied. It is assumed that if present best practice as it applies to fracture were to be fully implemented throughout, the economy would be represented by World III. The differences in economic activity between World I and World III then represent the presently reducible costs of fracture. By definition, the remaining differences between World III and World II are the presently nonreducible costs of fracture.

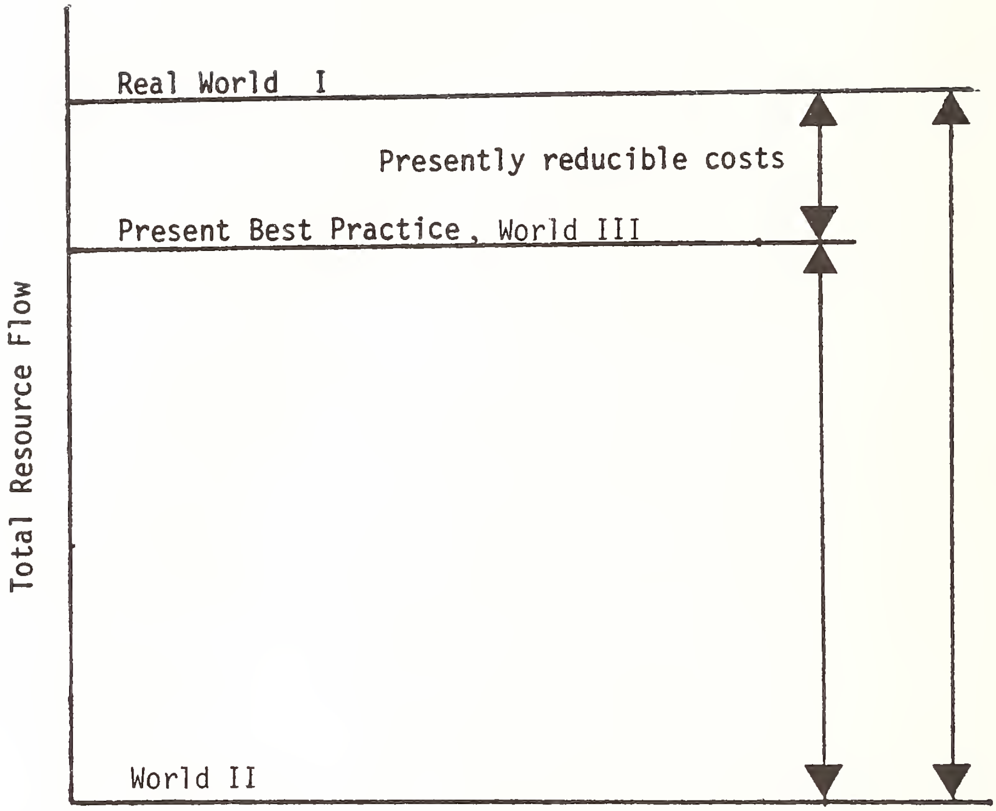

FIGURE 1. SCHEMATIC OF THE COSTS OF FRACTURE

To this point, the parallel with the "Cost of Corrosion" study is nearly complete.* A significant departure from that parallel has been purposely introduced into the present study as a result of a special need with which the NBS is faced. In order to determine the extent to which future investments in research and development might be expected to achieve still further reductions in the cost of fracture, a "World 'IV'" is defined.

It is recalled that Worlds I-III are a representation of what the U.S. economy would look like under the conditions imposed by the definitions. These Worlds are described in terms of interindustry transactions, capital requirements, final demands, and all the other elements of an I/O Model. Such is not, and cannot be, the characteristic of World "IV". World "IV" is based upon a futuristic estimate of ultimate best practice. That is to say, we examine an individual sector of the economy, taking as given the World III-World II difference as a measure of presently non-reducible costs in that sector. Then we pose the question: "To what extent, or by what proportion, could these costs be reduced by making and adopting the most reasonably expected technological advance?". The answer to this question would provide an estimate of future reducible costs within that sector.

The total result of querying all 150 sectors would provide a weighted summation of such percentages and an estimate of the cost saving that would accrue. This value would not be the same as that which would derive from a full I/O analysis of that future world for a variety of reasons. However, it would represent an estimate of the target benefits that can be achieved from advances in research in different fields.**

Given this approach to World "IV", it is now possible to define Future Reducible Costs and Future Irreducible Costs, as shown in Figure 2.***

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* As suggested earlier, and to be expanded upon later, the parallel is not exact, since we cannot realistically conceive of a world without fracture in the same sense as a world without corrosion. It is not necessary to belabor this point further, except to note that once the physical significance of our present World II is described, the conceptual problems vanish.

** It is important to note that the conduct of this study has resulted in an advanced application of Battelle's I/O method, and that such technical advances may make it possible to construct a variety of World IVs, each corresponding to the potential impacts of individual classes of research output. The detailed application of this approach would, however, require significant additional development of the overall model and is beyond the scope of the present study.

*** To this point, we have used the notation World "IV". The appearance of the quotation marks has emphasized the fact that this World "IV" is a different construct from Worlds I-III. The point having now been made, it is no longer necessary to confuse the notation. Subsequent reference to this World will omit the quotation marks.

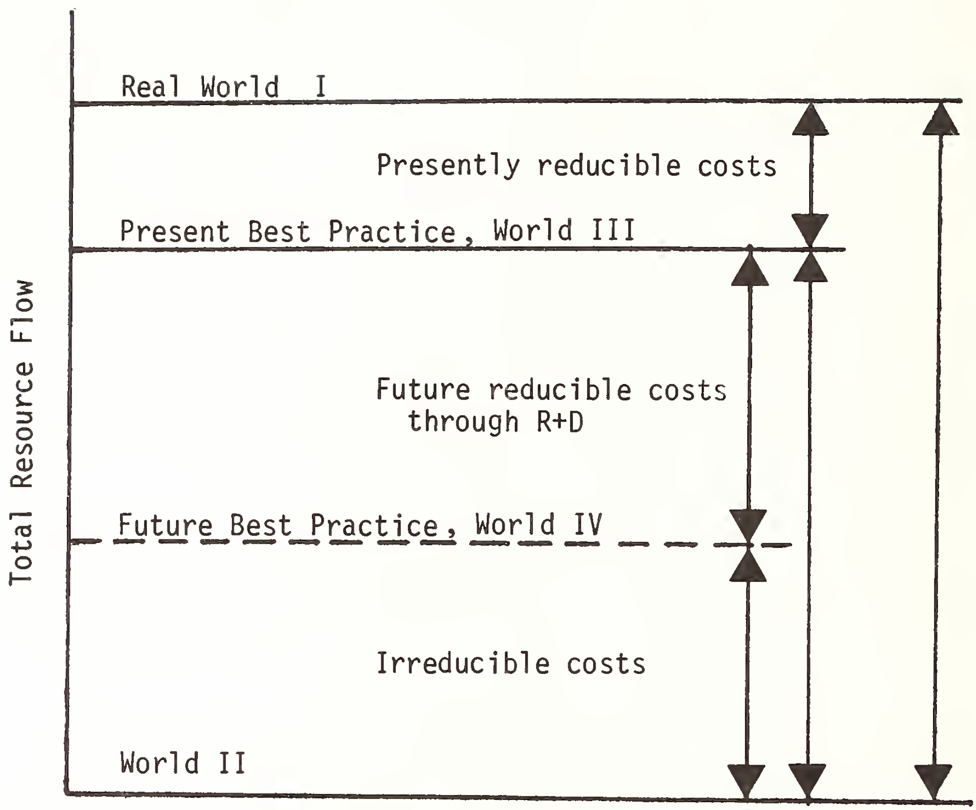

FIGURE 2. SCHEMATIC OF THE COSTS OF FRACTURE, WITH FUTURE BEST PRACTICE

Physical Significance of the Worlds

While many of the terms and concepts used in this study are quite straightforward (a full Glossary of Terms is included in Appendix A), the early stages of the program revealed considerable difficulties in developing mathematical and economic constructs which had physical significance. Furthermore, the problem was seen to be larger than the mere satisfaction and education of the Battelle and NBS project staffs. It was recognized from the outset that the proper conduct of the research would require much interaction with other resources outside of the two principal staffs. A large portion of the data to be gathered for the project would involve discussion with other parties (including additional Battelle researchers, industry representatives, other Federal government agencies, etc.) and it was obligatory that the specification of the Worlds be such that it could be quickly transmitted and absorbed during the data gathering process.

To this end, much effort was devoted to developing guidelines that would ease the data gathering activity, would permit the articulation of the results in terms most readily understood by the audience to which the project is directed (as well as the larger community of readers), and would maintain the closest possible relationship to the "Cost of Corrosion" study.

World I. There are no special considerations which have to be included in the definition of World I, since this World represents the real U.S. economy as it would have existed in 1978, under full employment conditions. All fracture-prevention costs are included, and fractures occur with costly consequences.

World II. Perhaps one of the most difficult concepts in the entire study relates to the definition and specification of World II--a world without fracture. In a world that was truly without fracture or massive deformation (although still limited by considerations of stiffness and some non-structural properties of materials), automobile bodies could be made from plain glass, balsa would replace oak and other sturdy woods, and the physical integrity of bridges, buildings and aircraft engine mountings would be taken as a constant, not requiring inspection. To adopt definitions of "No-Fracture" which are taken to the extreme would result in such absurdities that any conclusions drawn therefrom would be equally absurd. It would remove any semblance of practical realism from the study, and would result in there being such an enormous cost of fracture (World I-World II or even World III-World II) that it would appear that no amount of future research could have a significant impact on those costs. Thus, it was necessary to establish a definition of World II that, while highly idealized, still maintained at least a textbook significance*. The elements of this definition are as follows:

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* It is important to recognize that World II is a hypothetical construct which is "given" to use at no expense. We do not have to perform any work or expend any resources to attain World II. In World III, the only thing that is given is the knowledge that we may not otherwise have regarding best fracture-control practices; the truly best practices which might be applicable could well have been developed in one sector but not known in another. In order to attain World III, resources would have to be expended through education, technology transfer, etc. Similarly, the realistic approach toward World II would require expenditure of resources for both the advancement of knowledge and the dissemination and application of that knowledge.

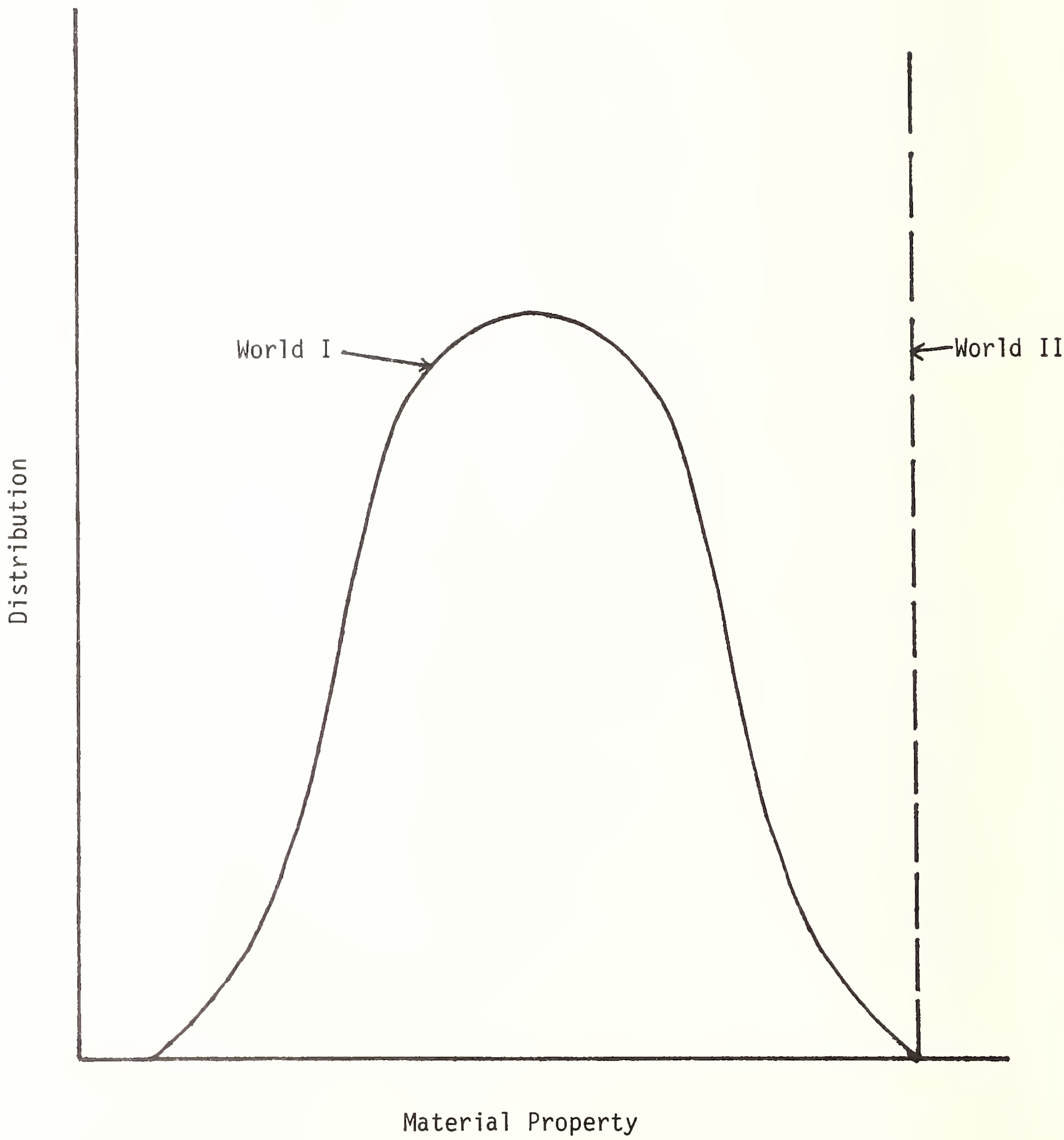

FIGURE 3. SCHEMATIC DISTRIBUTION FUNCTION FOR MATERIAL PROPERTIES IN WORLD I AND WORLD II.

(1) Each material's properties will have no variability, i.e., we represent mechanical properties in a delta function instead of a Gaussian or Weibull distribution (see Figure 3).

(2) Each material's mechanical properties will be defined as being four standard deviations above the mean of the distribution which is now achievable. The mechanical properties include the yield and ultimate strengths at the temperature of interest (see Figure 3).

(3) We assume no unfavorable influence on any one of a material's mechanical properties as we reduce the variability of its other properties.

(4) A material may be substituted if, in 1978, the primary reason for its not being used in that same application was its susceptibility to fracture.

(5) It is assumed that materials do not fracture under any conditions unless design specifications are exceeded.

(6) Design will either be load or stiffness limited.

(7) A safety factor of unity will be applied in any case.

(8) Design is carried out with perfect knowledge.

(9) Inspection for fracture relevance is not necessary.

(10) There will be no residual stresses.

(11) There will be no crack initiation, growth, or fracture, as a result either of processing or of service; fracture mechanisms not operating include fatigue, creep, radiation damage, and environmentally-assisted crack growth.

It is of particular interest to note criterion (4) above, which addresses the question of materials substitution. It will be recalled that the "Cost of Corrosion" program incorporated materials substitution in those obvious situations where such materials could have performed desired applications were it not for the fact that corrosion limited their usage. In a no-corrosion world, for example, it was not necessary to use stainless steel where other (less expensive) materials could just as well have been employed.

Similarly in this study, appropriate materials substitutions can be made in World II, where fracture events are not of concern or where a given material is not presently used solely because of its tendency to fracture. The determination of appropriate substitutions must be made on a case-by-case basis, but there are sufficient cases to guide each decision. For example, World II has embodied within it the assumption that cracks do not form under normal service conditions and, therefore, crack growth is not a consideration. It follows as a corollary that parameters such as toughness, impact energy, and fatigue crack growth rate have no meaning. Thus, in World II, one may use the stronger (but less fatigue-resistant) 7000-series aluminum alloys in aircraft, to replace the weaker (but fatigue-resistant) 2000-series alloys presently employed.

Examples of such potential substitutions in different applications are shown in Table 1. In spite of the potential for making many such substitutions, one must be cautious in selecting and applying the concept too broadly. The strict application of the materials criteria itemized above and a liberal substitution policy could lead to extreme situations which strain credibility. For example, under the conditions cited for World II, one might imagine the use of glass as a substitute for steel in a broad variety of applications. To do so, however, would represent a major restructuring of the overall American productive system and would completely disrupt the intent of the study.

Criterion (11) above raises an additional point of a conceptual connection between the present project and the earlier corrosion study. Crack initiation, fatigue, creep, and the like are time-dependent processes: changes in either the micro- or macrostructure which are progressive after some defined benchmark time t=0. The process of corrosion is exactly similar, there being no corrosion of even the most oxidation-prone materials at t=0. Thus, in terms of time-dependent processes, World II in either case represents material conditions which are extant at t=0 and which remain as such during usage.

World III. The determination of technical best practice and its application to the computation of World III represents problems just as complex as those described for World II. In simplest terms, "best practice" can be described as that combination of presently known materials, processes, and technologies that will deliver the goods and services of the U.S. economy at lowest overall fracture-related cost to society. World III implies that, on the whole, devices and structures are not only produced using the most advanced techniques known within a particular industry, but are also employing techniques that have been developed for other industries. For example, methods of bridge construction in World III take advantage of the concepts that have developed both within the bridge industry and within the aircraft industry.

In addition, best practice goes beyond that practice which is deemed sufficient for compliance with imposed regulations. Furthermore, best practice can include materials substitutions which are presently technologically acceptable. There are a number of cases (see Table 2) in which alternative materials can be used to deliver the same function. One aspect of the determination of World III is the examination of potential materials substitutions insofar as they contribute to overall best practice.

World IV. As noted earlier, World IV is not a detailed picture of the economy in the same sense as Worlds I-III, but is the conceptual basis for an estimate of the percent of presently non-reducible costs of fracture which

TABLE 1. EXAMPLES OF POTENTIAL WORLD II MATERIALS SUBSTITUTIONS

Application	Substitutions
LNG Tanks	Quenched and Tempered Steel for 9-Ni Steel
Bridges, Pressure Vessels, etc.	Non-Weldable Steel for Weldable Steel
Airframes	7000-Series Aluminium Alloys for 2000-Series Aluminium Alloys
Windshields	Non-Tempered Glass for Laminated Glass

TABLE 2. TYPICAL MATERIALS SUBSTITUTIONS APPLICABLE WITHIN THE CONTEXT OF WORLD III

Application	Substitutions
Light/Telephone Poles	Wood/Steel/Cement/Aluminium
Eyeglasses	Glass/Plastic
Drinking Glasses	Glass/Plastic
Roads	Cement/Asphalt
Shopping Bags	Plastic/Paper
Dishes	Crockery/Ceramic-Polymer Composites/Glass
Sports Equipment	Various, depends on application
Sewer Pipes	Cast Iron/Plastic
Hot Water Pipes	Plastic/Copper/Iron
Automobile Fan Blades	Fiberglass/Metal
Automobile Bumpers	Aluminium/Steel
Tire Belting	Steel/Plastic/Glass
Railroad Ties	Wood/Cement

might be reduced through new and/or continuing research. In approaching a determination of World IV, one must consider the following types of questions:

(1) Given the difference between World III and World II, the presently irreducible cost of fracture in each sector, what percentage of that cost might be reduced through additional research?

(2) Of that figure derived in the answer to Question #1, what fraction may be attributable to research on materials? On design? On reliability? Or, on production and fabrication?

(3) What types of research are required to accomplish the goals noted in Question #2 as they apply to these areas.

Special Attention to Factors Beyond Scope

In the preceding discussion on World II, criteria were defined which concentrated basically on the intrinsic physical properties of materials and their applications. It will be recalled that these criteria were imposed for two reasons: (1) to provide a basis for understanding the physical significance of World II, and (2) to attempt to maintain parallelism with the corrosion study. This latter factor is generally deemed necessary in order to provide even a qualitative and conceptual connection.

From the outset of the program, it was recognized that complete parallels could not be drawn for, as noted earlier, one cannot make the absolute translation from "no-corrosion" to "no-fracture"; to have done so would have resulted in a **reductio ad absurdum**. However, through use of the definition of "fracture within scope", one can maintain whatever parallelism is deemed appropriate without sacrificing the intent and integrity of the investigation.

Central to the delimiting of scope is the criterion noted above that "(5)...materials do not fracture unless design specifications are exceeded" (emphasis added). This statement is critical to an appreciation of both that which is included or excluded from the study, and that which lies within the purview of the National Bureau of Standards and the community of other organizations who are concerned with the fracture of materials and the failure of structures.

The emphasis noted here stresses the fact that there are classes of materials or structural failure which can occur but which are not subject to study within the scope of the program. To be sure, we note that fracture does occur in World II. However, that fracture includes those cases for which design specifications are exceeded. Included among such cases are those, for example, which are caused by acts of terrorism, violence, or vandalism; collapse of structures caused by natural phenomena (e.g., earthquakes, floods, tornadoes) where the force of such phenomena exceeds that for which the structure was designed; fracture of materials or structures that result from drunken driving; and the like.

That these types of fractures still occur in World II derives from the following arguments. It is first known that such events occur in the real world, World I; broken windows are replaced, some purposefully broken goods are repaired, etc. By including such fracture in both Worlds I and II, the corresponding costs are eliminated from the difference between Worlds I and II, and it is that difference that measures the total cost of fracture.

As a further consequence, this class of events is thus excluded from consideration when one deals with the question of World IV. That this should be the case is appropriate, for World IV raises the question of the types of research which might be undertaken to reduce the costs of fracture. That research which might be directed toward eliminating the cost of those fractures which arise from causes including vandalism, terrorism, etc., is certainly not within the framework of this study or the mandate of the National Bureau of Standards.

The specification of conditions defining World II are such that there is no dilemma regarding what may be termed "beneficial fracture". Such beneficial or purposeful fracture includes chopping wood, breaking of windows for emergency entrance or exit, the opening of sealed containers, and the like. In each case, fracture would not occur unless useful and socially acceptable ends were achieved. Such fractures are obviously desired, their occurrence is accounted for in World II, and they are thus eliminated from consideration in the World I-World II and World III-World II differences and analyses.

One might argue at this point that "acts of ignorance or neglect" should also be cited as out-of-scope; that failure to follow proscribed operation or maintenance procedures should be counted in World II and therefore eliminated from the World I-World II or World III-World II differences. However, such elimination would deny the fact that fracture prevention is a process which involves both "hardware" (the materials and design) and "software" (the instructions). Just as improvements in materials and processes might show promise in reducing the fracture-proneness of selected components, so also might improvements in maintenance or operation manuals reduce the probability of error and the possibility of fracture. Similarly, improvements in the arrangement or display of warning gauges (e.g., operator indicators on aircraft, machining equipment) can be seen to reduce the probability of improper operation.

It will be noted later (in particular connection with the data which provide input to the Supplemental Models), that the collection and analysis of any information related to the World I and World II constructs must be viewed in terms of the considerations: (1) are the data relevant to fracture; and (2) is the fracture within scope? It is only with an appreciation of these basic criteria that one can approach the overall complex problem with useful consistency.

III. GENERAL APPROACH

The introductory comments in this report noted the necessity of taking a macroeconomic approach to a determination of the costs of fracture. That such should be required is a consequence of the interrelations among all the productive sectors of the economy, for costs are distributed in a complex weave which is not unlike the progression of disturbances in a closed pond. Just as a pebble generates waves in all directions, and the reflection of such waves produces reinforcements and troughs which are influenced by the geometry of the perimeter, so also does a change in a single production process or industry have an impact throughout all other portions of the economy.

One need only consider, qualitatively, the stream of consequences which could follow from the replacement of wood, as a material of construction, with plastics. The lumber industry would decline; establishments which provide saws, planers, and chippers would undergo major modifications in their product lines; land would be diverted from forestry to agriculture or other uses; wood adhesives would be replaced by polymer adhesives; and many established processes and producers would become extinct.

Conversely, such a substitution would give rise to massive expansions in the production of plastics and in industries which supply raw and precursor materials; there would be an increase or modification of the business of producing specialized capital equipment, and so on down the line. The demand for fossil fuel materials (coal and crude petroleum) would skyrocket, as well as the supply of by-products or waste; and the competition for such fossil materials could have a significant impact on their availability to satisfy needs for energy. Clearly, the event postulated here would result in changes throughout the national economy, (both structurally and regionally), with some "winners" and some "losers," depending on the nature of resultant changes in economic base, employment shifts, etc.

No simple microeconomic tabulation approach can assure that one could account for the total economic impacts associated with even a single technological change. Certainly, no such approach could be expected to deal with the simultaneous impact of a large number of departures from the present system. It is immediately apparent, from the description of the present program and the definitions of the "Worlds," that a more sophisticated approach is required. The transition from World I to either of the other Worlds represents a substantial and far-reaching change in the economy, and no lesser tool than a complete Input/Output model would suffice.

What is Input/Output?

Most simply stated, the Input/Output (I/O) Model is a straightforward series of relationships that combine the output (or "sales") of one industry, group of industries, or productive process with the inputs (or "purchases") of all other industries, groups of industries, or productive processes. For example, a given company within the electronics industry may sell its output as follows:

(1) A portion of its output (say, semiconductor components, resistors, capacitors) will be purchased by the industry which assembles and distributes video games or home computers. Another portion will be purchased by industries which produce controls for home appliances. These are examples of purchasers who use electronic components as "intermediate inputs" in their own business.

(2) Another portion of the electronic industries' outputs (e.g., computers) may be purchased annually as capital equipment by other industries, either for application to process control or as accounting tools. Unlike intermediate inputs, capital is not consumed or changed by its use in the productive process. The capital equipment sold in an average year must provide both for the replacement of obsolete or worn out equipment and for the growth of the capital-using industry. The total capital held by the buying industry also includes any redundant capital (that is, capital held in reserve for emergencies).

(3) The electronics industry also sells spare parts and maintenance and repair services to industries using its capital. These sales are treated in the same manner as the intermediate inputs (Item 1, above).

(4) The electronics industry also sells its product to final buyers who are not part of the productive process, such as private consumers and government agencies. In addition, it exports goods for use and consumption in all of the above forms, thereby finally removing them from the U.S. economy.

Taking each of these classes of transactions in turn, the simplest expression for the distribution of a single company's output is given as:

$$x = ax + gbx + rbx + fd \tag{1}$$

where

a = that portion of output which is used as intermediate inputs and as purchases of maintenance and repair parts and services

b = the capital held by the buying industry

g = the fraction of that held capital which is purchased to provide for annual growth

r = the fraction of held capital that is purchased for replacement purposes

fd = the portion of output that is purchased by final users and is thereby removed from the U.S. productive activities.

We may now write a similar equation for each of the productive elements of the economy, say N in number, and sum them for the total economy. The collection of all these equations can now be expressed as:

$$[X] = [A][X] + [G] \circledast [B] [X] + [R] \circledast [B] [X] + [FD] \qquad (2)$$

where the symbol $\circledast$ represents the Kroenecker multiplication of matrices (i.e., a cell-by-cell multiplication of corresponding elements, as opposed to the standard matrix multiplication), and

X = a vector of total output

A = a matrix of direct technical coefficients

B = a matrix of capital/output coefficients

G = a full matrix of industry growth rates, with each entry in any column being equal to the growth rate of that column sector

R = a matrix of capital replacement rates

FD = stipulated noncapital final demand (personal consumption expenditures, government expenditures, exports, and inventory change)

Equation (2) states that an industry's total output is distributed among intermediate consumers, purchasers of capital (for both growth and replacement), and final consumers. The term AX is the output consumed by intermediate users, $B \circledast GX$ is the output which is allocated to growth capital, $B \circledast RX$ is the output allocated to replacement of worn out capital, and FD is the output accruing to final consumers. Equation (2) may be solved for total output, X, by the following:

$$X = [\ I - A - B \circledast (G + R)]^{-1} * \overline{FD} \qquad (3)$$

where $[I - A - B \circledast (G + R)]^{-1}$ is an inverse matrix.

Equation (3), often termed the dynamic inverse, is key to the I/O formulation used in this study. It treats the capital stock coefficients $B \circledast G$ and $B \circledast R$ as if they were flow coefficients and combines them with the direct technical coefficients, allowing capital purchases to be a function of stipulated final demand. The resulting inversion permits the specification of the output required from each sector, both directly and indirectly, to support the production of one unit amo unt of final demand for the products of each other sector.

It is apparent from inspection of Equation (3) that changes in the purchases by one industry of the output of another industry (reflected in the change of a single entry in the A matrix) has an impact which diffuses throughout the economy. The simple mathematics of matrix operations shows that each element of an inverted matrix is altered by a change in any element of the original matrix. Hence, any change in technology which influences one industry's purchase from another will affect the outputs of all other industries. This approach permits one to systematically inspect each element of each matrix and isolate the influences of changing purchasing patterns.

A more detailed description of the I/O Model and its implications will be found in Appendix B.

The Concept of Sectors

To this point, our discussion has been in terms of purchases and sales between companies or industries. Neither such reference, however, permits a detailed inspection of productive processes and the technologies which support them. Battelle's approach to I/O takes a different form, with this difference being manifest in two ways. First, the model is based upon the technologies of production and the manner in which technological change impacts the economy; second, this information is collected in the form of expert knowledge. Thus, it does not concentrate on single companies or SIC codes; nor is it concerned with the varied mixes of products that might be marketed by diversified companies or conglomerates.

Instead, the Battelle I/O Model defines "sectors" in terms of the technology required to produce a specific set of outputs, where the spectrum of outputs may be very broad or very narrow, but the productive processes are essentially similar. Also, the Battelle approach does not rely upon existing, historical statistics (collected by the ex post or survey process) to ascertain relations between and among sectors. Instead, the process (termed ex ante) depends upon expert opinion and knowledge regarding the extent to which intersectoral transfers are involved in the technologies required to produce the outputs of every sector.

Sectoral Format

The standard format of the Battelle Input/Output Model divides the productive economy into 126 productive sectors and six final demand subcategories. This format is, however, readily altered by the aggregation or disaggregation of specific sectors or subcategories to provide the kinds and degrees of detail needed to deal with particular problems. For the present study of the costs of material failures (fractures and deformations) in the United States, the sectoral format has been modified to consist of 150 productive sectors and eight subcategories of final demand. These elements are set forth and defined in Appendix C.

Although the standard sectors of this I/O table provide an excellent framework for general economic analysis, they have some obvious shortcomings when used for such special analyses as those of the earlier Corrosion Study and the present Fractures Study. In the former case, it proved desirable to provide much greater detail with respect to metals, paints, coatings and special services, all specifically corrosion-relevant. Similarly, in the case of fracture, particular fracture-relevant detail is required. With respect to materials subject to fracture, there are, for example, (a) fabrication processes which cause fracture or in which fractures often occur, (b) end use industries in which fracture-caused accidents ("events") are particularly troublesome, and (c) certain services which are used largely because of fracture exists.

Materials

The scope of this study embraces a wide range of materials: metals, glass and other ceramics, polymers, concrete, wood, and composites, each of which represents a different history and design philosophy. Minimally, we have striven to provide separate sectors for the production of each of these, as well as for the more important product groups into which each enters. Material sectors are important in the column (process) sense because variations in their input structures may exert significant influence upon their behavior in use; they are also important in the row (use) sense because the fracture-related characteristics of the material may pose special problems for every use into which they enter (e.g., the brittleness of glass).

Moreover, technology which is adopted or changed in order to reduce fracture will affect the amounts of particular materials that are employed in particular industrial processes. Thus, when going from World I to World II, we would expect a general change in the thickness of materials being used. For instance, if steel generally had the characteristics and was used in the manner hypothesized in World II, approximately half as much would be needed in many manufacturing processes.

Fabrication Processes

In the Battelle model, a sector is defined as an industrial process or group of processes producing a specified collection of products. Therefore, if certain products are especially fracture-prone or fracture-relevant, in terms of either the process that creates them or the uses into which they enter, these products ideally should be segregated into a single disaggregated sector. This is especially true if there are other products in the same original sector that are not so relevant. For this reason, stone, clay and glass products have been extensively disaggregated. Standard sector 6.01 (Glass and Glass Products), for example, has been disaggregated into four subsectors in order to isolate flat glass, glass containers, and auto/truck windshields from all other glass products. Not only are each of these three product classes highly fracture-relevant in the (row-wise) uses into which they enter, but the processes by which they are produced (column-wise) are subject to alteration for fracture-related reasons.

End Uses

When we think in terms of end uses that are especially fracture-relevant, transportation industries quickly come to mind. Fracture-caused or complicated accidents ("events") are especially prevalent in these industries and attract a great deal of public attention when they occur. For this reason, construction (which includes both new construction and the maintenance and repair of corresponding output) has been extensively disaggregated in order to isolate that which goes into railways, pipelines, and highways, among others. It happens that the transportation industries themselves, along with the industries providing their carrier capital, are sufficiently disaggregated in the standard sectors so as not to need further treatment.

Note on Military/Civilian Uses. In connection with end uses, attention is called to a set of disaggregations that was considered, but not undertaken. These relate to the special design problems involved in military land vehicles, naval vessels, and military aircraft. It was initially considered that each of the sectors in Group 11, Transportation Equipment, be disaggregated so as to separate military and civilian equipment. It was thus assumed that military equipment was produced by different technologies and was generally treated as more fracture-sensitive than the non-military equipment produced within the same sector.

If this suggestion were to be followed consistently, it would have led to the conversion of five sectors into ten, as follows:

11A01 Military vehicles & parts

11B01 All other motor vehicles & parts

11A02 High-performance military aircraft & parts

11B02 All other aircraft & parts

11A03 Armored ships & submarines

11B03 All other ship & boat building & repairs

11.04 Locomotives, rail cars & streetcars

11A05 Guided missiles & space vehicles

11B05 Military tanks

11C05 All other transportation equipment (motorcycles, trailer coaches, etc.)

It was decided that none of these military disaggregations be undertaken for the following reasons:

1. In each sector, as that sector was originally established in the several World I matrices (intermediate, capital, useful life, growth, and replacement), the coefficients were approximated as weighted averages of military and civilian technologies. In most cases, the total sector outputs are probably dominated by civilian products.

2. The costs of fracture are to be measured as the differences between Worlds I and II, III and II, or I and III, and not as the absolute values in any Worlds. Therefore, the important question is not "does military technology differ from civilian technology in any World?" Instead it is "is the change from World I to World II, etc., proportionately the same or different in military and civilian technologies?" For example, the metal in a civilian ship might be .25" thick; and in an armored ship, it might be 4.0" thick. If elimination of material and design uncertainties in going from World I to World II allows a 50 percent saving of metal in both kinds of ships, they would be treated alike and need not be separated.

3. In general, we can assume that the technological differences between military and civilian forms of the same item flow from differences in function and tend to relate uniformly across all "Worlds". To the extent that this is true, there is no need to disaggregate sectors into military and civilian subparts, since it is the between-Worlds differences, rather than the within-Worlds differences, that are important.

4. It should also be noted that the final demand vectors will show separate military and civilian Federal government expenditures on the products of every sector. This will permit attribution of fracture costs to national defense without further disaggregation.

Other End Uses. There are some other end uses, however, those which deal directly with fracture control, that had to be taken into account. An important one was the separation of fracture control instrumentation [e.g., strain gauges, nondestructive evaluation (NDE) equipment] from other scientific instruments. Another was the similar disaggregation of R&D from other business and professional services and its further disaggregation into fracture related and other R&D. This latter disaggregation permits isolation of those activities which are directly related to the objectives of the program: namely, the identification of specific fracture-relevant R&D and its future impact on the cost of fracture.

Special Services

Fracture-related end uses, such as those just discussed, tend to merge into the group of special service disaggregations that are important because of their relationships with fracture prevention, control and/or consequences. Insurance, for example, has been isolated for this reason. Automobile repair (a standard sector) has obvious fracture-relevance; and for similar reasons, repair services have been separated from personal services.

The Data Collection Approach

The general approach to the development of Worlds II and III, given the characteristics of these Worlds and the existing specifications of World I, requires that consideration be given to those changes in all the matrices which would be expected under the conditions of World II and World III. While specific details relative to the data collection will be presented in Chapter IV, it is worth noting here that emphasis must be placed on the manner in which a technological change (in this case, for example, changes regarding material fracture) would result in a different pattern of purchases. Thus, it is important that data collection proceed with a knowledge of present practice and a sensitivity to the rationale which ties one sector's output with another sector's input needs.

The classical **ex ante** approach to this type of data collection generally rests on the so-called "expert interview." It will be shown that this method was augmented in this study by the development of a more generalized approach which should find further applications in future investigations of this type.

Supplemental Models

The consequences of materials fracture, as noted in the opening chapter of this report, can be highly visible and tragic. Headline-making events occur which result in consequences ranging from death and severe injury to diverse long-term impacts on both individuals and society. The loss of hundreds of lives in airplane disasters, mine collapses, and bridge and scaffolding failures--some of which are precipitated by the breakage of relatively small components--give rise to hearings, investigations and lawsuits. There is no question that such events result in direct and indirect costs. Additionally, they carry both measured and imputed costs.

In addition to the costs which accrue to the victims and direct survivors of such events, there are other, more peripheral costs which are incurred as a result of such events. When a bridge collapses, there are costs associated with business interruptions, excess fuel used because of detours, and general inconvenience, among others. When an airplane crashes--regardless of the reason--there are business losses (often temporary) to the airline industry as well as a variety of "inconvenience" costs*. When a train derails or an oil tanker breaks up, there are additional costs associated with lost cargo, costs of cleanup of spilled wastes, costs associated with environmental degradation, and costs of loss of use of affected facilities.

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* While these ancillary impacts and their associated direct and imputed costs are important, such costs are not, for the most part, included in the present analysis. The determination of these costs constitutes a major project in itself and is not within the scope of the present study.

Because, in part, of the visibility of such events, this study has been expanded beyond an assessment of the pure technological cost of fracture prevention, as had been done in the earlier NBS study of the cost of corrosion. To this end, a set of Supplemental Models was developed to estimate these additional costs, starting with the premise that a variety of events are the result of fracture of some component, that such fracture causes an event rather than being caused by the event, and that such fracture is within the scope of the project.

It has been established, to this point, that the economic costs of fracture are composed of two major categories: those costs that are incurred in anticipation of material fracture, and those that accrue as a result of fracture. The Input/Output Model accounts for the majority of the technological costs associated with fracture prevention. The Supplemental Models account for the costs which result from fracture, including losses of cargo, human pain and suffering, environmental degradation, and other imputed costs.

Four supplemental models were used to evaluate the above consequential costs of fracture in the U.S. economy: the Events Character Model (ECM), the Injury Cost Model (ICM), the Property Cost Model (PCM), and the Environmental Degradation Model (EDM). The overall flow among the models is presented in Figure 4. The Events Character Model determines the number of fracture-related events, the average consequences of each fracture-related event, and the severities of their consequences. The Injury Cost Model determines a dollar cost of injury consequences, including such costs as hospital and drug costs, as well as those associated with pain, suffering, and death. Similar costing procedures are used in the Property Cost Model and the Environmental Cost Model. Details concerning the input characteristics and types of results are briefly summarized below. Further detail is provided in Appendix E.

It should be noted in connection with the Supplemental Models that they vary from the I/O Model and from each other in their levels of vigor and/or formality. The term "Model" is used in economics to describe any intellectual construct or abstraction that provides a simplified framework for the examination of reality. In this study, the I/O Model is quite rigorous in its formulation and quantification. Some of the Supplemental Models (e.g., the injury Cost Model) are almost as rigorous. Others (e.g., the Environmental Degradation Model) are distinctly less so. The degree of formality characterizing a model is a function of the availability of "hard" data for use with it and of the necessity for imputations of nonmarket costs to elements thereof.

Events Character Model

Input to the ECM is a list of fracture relevant events which may be classified into five basic types of accidents: transportation-related, work-related, home-related, public-related, and other events. The outputs from the ECM include tabulations of the number of fracture-caused accidents by event, the average number of injuries and deaths per event, the number of each of various types of property damaged, and finally, a determination of the average environmental consequences of each accident.

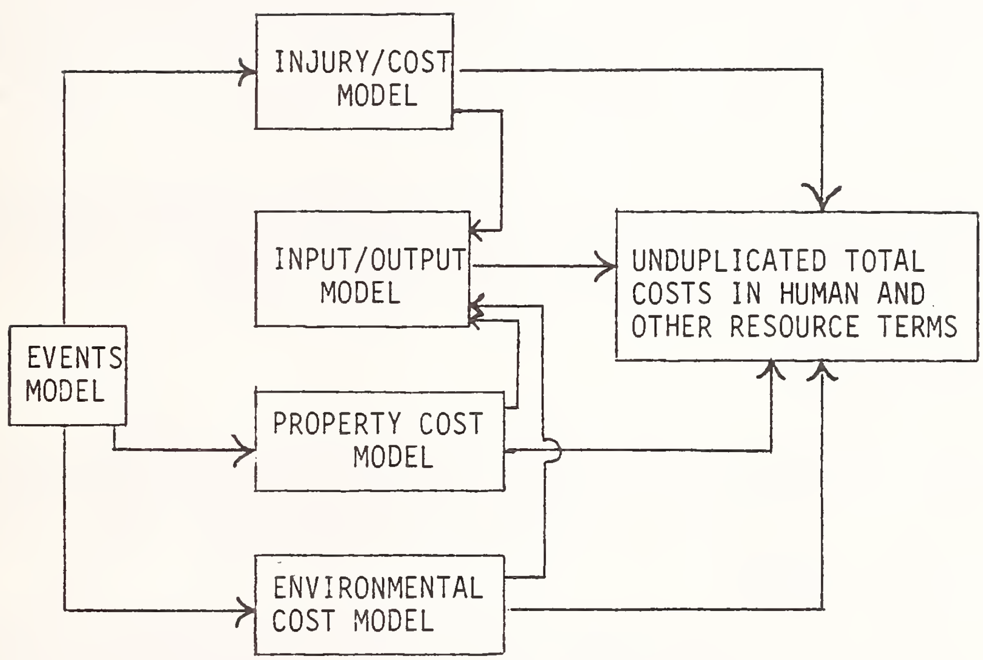

FIGURE 4. FLOW AMONG MODELS

The availability of the data required to run the ECM varied considerably both by event and by level of detail of the consequences which resulted from that event. All data were collected for the "average" year 1978; i.e., in cases where the frequency of occurrence was low, data were collected for several recent years and averaged.

Injury Cost Model

The Injury Cost Model (ICM) was utilized in conjunction with the subcontractor T+E.* This model, which was originally developed for the U.S. Consumer Product Safety Commission, concerns accidents and failures involving consumer products, and uses a disaggregated approach to estimate the total social costs of injuries. In the model, total injury costs were partitioned into a set of eleven cost components, each of which was then independently estimated.

The inputs to the ICM consist of the numbers of deaths and human injuries developed by the ECM. ICM output consists of detailed cost estimates of human injury and death due to fracture-caused accidents. Values of costs by event were then summed to produce total aggregate costs.

Property Damage Model

The Property Damage Model (PDM) provided cost estimates (in 1978 dollars) for all property identified as damaged in the ECM. The method used to value the cost of property damage was a simple listing of each item of property damaged. Where severity of the damage was known, it was included in the costing of the damage.

Inputs to the PDM were the average numbers and types of property damage per accident by event, and the number of occurrences of the accident due to fracture. This model provided approximate dollar cost estimates for all the items damaged by fracture-related accidents. Nonrecoverable property damage (such as cargo losses at sea) were assigned on a sector-by-sector basis to final demand in the I/O Model.

Environmental Degradation Model

The Environmental Degradation Model (EDM) measured costs (in 1978 dollars) of total environmental cleanup and environmental degradation due to fracture-caused accidents. Inputs to EDM were the types and severities of environmental consequences associated with fracture-related accidents, and the number of such accidents, by event.

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* Technology + Economics, Inc., Cambridge, Massachusetts.

Use of Supplemental Models

As noted earlier, the Supplemental Models are designed to specifically measure costs which accrue as a result of fracture-relevant events. Often, the Supplemental Models deal with events that are highly visible to the public. To the extent that an event is a newsworthy item, fracture may also be a sensitive issue. Occasionally a spectacular fracture event captures the public attention and forces recognition of the fracture problem. However, such events do not occur frequently and, as will be seen later, their overall average annual cost is low compared with the total cost of fracture. Thus, even though certain fracture events are highly visible, emotional, or spectacular, they do not account for a large share of the total cost of fracture to society. This must be recognized to place the Supplemental Model results into perspective.

Great care must also be exercised in defining the "allowability" of events within the context, scope, and objectives of this study. As will be detailed in Appendix E, the selection of events results from what is essentially a three-stage screening approach:

(1) the compilation of all events within a particular class (e.g., transportation, home, industrial, etc.);

(2) the identification of a basic cause of the event, isolating those events which were precipitated by fracture; and

(3) the selection of those events in terms of fracture as defined within the scope of the program.

Steps (1) and (3) are straightforward, the first being facilitated by the on-going accounting procedures of various Federal, state, and local government organizations, as well as private "watchdog" organizations and public interest groups. The third step follows from the definitions of scope (see the earlier discussion on World II and the attendant remarks regarding those types of fractures which still occur in a no-fracture World).

There is no doubt that the second stage above is the weakest link in the chain since, for the most part, there are few classes of events for which sufficient investigations are carried out to determine root causes. The heavily regulated industries (railroad and air transport) undertake detailed studies in an attempt to identify those initiating factors which lead to disasters.* In stark contrast are the analyses carried out in connection with

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* Such detail, for example, permits identification of causes in terms of materials, designs, or even maintenance and repair procedures. It is precisely because of such detail that steps can be recommended which deal with the "software" approach to fracture prevention, rather than only "hardware" changes.

the vast majority of automobile accidents, where the sheer number of events and different levels of professional investigatory expertise preclude the specific identification of fracture within scope as the principal contributing factor.*

As will be seen in the more detailed description of the events models (Appendix E) and the results from the Supplemental Models (Chapter VI), the total cost of fracture attributed to events is a relatively small proportion of the overall costs of fracture. While there is no question that the total costs related to automobile accidents is considerable, (see Table E-2, Appendix E), after going through the screening process noted above it will be found that only a very small portion of those costs is clearly attributable to fracture within scope.

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* A common account of, say, an automobile accident might note that "the steering column broke and I lost control". Whether, in fact, this was the sequence of events, or whether the accident occurred from other non-fracture related or out-of-scope fracture causes, is seldom determined unless significant litigation is involved.

IV. SPECIFIC INPUT/OUTPUT METHOD

In applying the general approach to the data actually going into the model, changes from the plan were inevitable. Data were not always available as planned; personal capabilities and understandings varied from those expected; conceptual problems often arose when theory was confronted with reality; and there was an ongoing learning experience that deepened our understanding of what information had to be obtained and from where. In this chapter, we take up the actual steps in data collection and introduction into the Input/Output (I/O) model, in sharp contrast to the plans and expectations around which the research program was built.

In modifying World I coefficients to fit the hypothesized World II and World III conditions, the original program had envisioned the collection of information from selected industrial experts on a sector-by-sector basis that would be introduced in the form of column-specific changes in the A, B, and U matrices and noncapital final demands*. This approach can be termed the standard (or classical) ex ante approach. As we will show, however, circumstances necessitated a specific and significant extension of method, the use of what we have termed "row-rules". This concept marks a distinct departure from the method used in the earlier study of the cost of corrosion.

In the case of corrosion--as probably would also be the case in many other similar research programs--emphasis had to be placed primarily upon column, rather than row, adjustments. The significance of these differences is taken up below. They stem from the fact that, so far as corrosion is concerned, each sector (industry) creates a specific environment that affects the rate at which employed capital (plant and equipment) can be expected to deteriorate. Although not entirely absent from fracture considerations, this specificity of relevant sectoral environment is not a dominant aspect of the study, for which reason much more of the technological modification can be introduced by the row, rather than by the column.

The Nature of Simulation Adjustments

In the Battelle method of estimating costs of degradation (i.e., corrosion or fracture), adjustments are made in the elements of the I/O model to alter them from World I (real world) conditions to the conditions hypothesized to exist in World II (no degradation) and World III (best anti-degradation practice). The directions and degrees of the adjustments are determined as functions of the World I conditions and costs that are thought not to characterize Worlds II and III. In the corrosion study, it was felt that many sectors created an especially destructive environment--e.g., coal

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* The specialized terms (e.g., "A matrix", "U matrix", "Final Demands", etc.) are defined in the Glossary, Appendix A.

mining, pulp and paper--in World I. Therefore, in order to make adjustments to no-corrosion or best practice conditions, the changes were introduced by the column as a whole, not by the row. In other words, all capital and all technologies in the paper industry or in coal mining were exposed to a common corrosive environment; but there was nothing particularly corrosive that happened specifically to motor vehicles alone, regardless of where used. Thus, in terms of I/O technique, the changes were introduced by the column, and not by the row. Since the World I coefficients had originally been collected and refined by the column, it was decided to utilize the same, standard, ex ante approach in generating World II and World III differences as had been used for World I.

As will be noted below, the column-oriented approach was not as applicable in the present study. While there are, to be sure, many sectors having both capital and productive processes which would be altered in World II or World III, it was determined that a significant portion of the changes could be accounted for in terms of row-input manipulations.

In addition, two other features of this modification in approach are important. First, while the initial program plan called for detailed inspection of only those sectors deemed to be of highest priority (as defined in consultation with NBS and among the project team), the emphasis on a row approach permitted giving attention to all sectors. Second, the row approach provided consistency and cohesion throughout the analysis, linking the approach with both the scope and the objectives.

The Ex Ante Approach to Corrosion

In order to make World II and World III modifications in the Corrosion model, all the sectors were grouped in terms of their dominant technologies. Metal producing sectors were grouped together, for example, and were grouped separately from the metal fabrication sectors, etc. In this way, the more than 130 sectors of that model were distributed over some 15-20 industry groups, each of which was assigned to a one or two man data-collector. As information was collected, it was injected into the several matrices by the column to give effect to the interindustry differences with respect to technological practices and exposures to corrosive environments.

The Planned Approach to Fracture

In the original work plan, the list of I/O sectors was to be arrayed in terms of fracture-relevant importance and assigned to individual data-gatherers (chosen from a group of Battelle staff scientists and engineers) for literature searches and industry interviews. It was planned that all the high-priority sectors would be researched before any of the second-level sectors, etc. Insofar as time and resources would permit, all the matrix modifications from World I to Worlds II and III would be based on these data; and most, if not all, changes would be made on a column-by-column basis. This procedure was generally consistent with the ex ante work that had been carried out earlier, including the matrix modifications made in the corrosion study.

Column-Oriented Data Gathering

The sectors of the fracture study model were distributed in terms of five priority groups:

First priority: 25 sectors
Second priority: 31 sectors
Third priority: 24 sectors
Fourth priority: 40 sectors
Fifth priority: 29 sectors

Three data-gatherers were chosen--each representing a different field of specialization (metallurgy, ceramics, and polymer chemistry)--and all the sectors were either distributed among them or placed into a fourth group for special consideration by the project's senior staff.*

The Emergence of Row Rules

It was originally planned that the data-collectors would be "debriefed" sector-by-sector by three senior economists who would then rework the information into the actual (cell-by-cell) matrix modifiers. It was later realized, however, that this procedure was not cost-efficient: the complexities of many sectors, the difficulties in sensitizing even the most knowledgeable industry experts, and the major conceptual differences between the corrosion study and the present program all contributed to inefficiencies in both collecting the data and debriefing the data-collectors. As a result, the overall procedure was modified in three respects:

- A series of row rules was developed which would facilitate the process of introducing appropriate changes into the matrices for World II and World III; in all cases, the nature of the rules and magnitudes of the changes were guided by information already obtained by the data-collectors.

- The six-man senior project staff team (representing a collective broad range of expertise, including the physical and engineering sciences, process development and engineering, and economics) was convened as a device for

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* In anticipating the complexities of data collection, it was originally intended that emphasis would be placed on only the first three priority areas with only a cursory examination, if any, of the remaining sectors. The later definition and development of the so-called "row rules" permitted examination of all sectors.

- Reviewing and completing the column-oriented work, begun by the data-collectors

- Carrying out, either by their own effort or by special assignments to the data-collectors or additional senior staff, incompleted column-oriented matrix changes

- Reviewing relevant data, gathered by the data-collectors and others, and establishing the row rules and the exceptions thereto,

- The expertise of a most-experienced Battelle engineer/industrial economist was utilized as a source of additional information for the senior group.

Ultimately, following the initial procedures as modified above, column-specific modifications were made for 60 sectors in the A-matrix; and row-specific rules and exceptions were established that would apply across the entire A-matrix and perhaps to other matrices and/or final demand. It should be noted in this connection that all the row rules were applied to the column-specific sectors at the same time other adjustments were made in them in order to minimize procedural opportunities for error.*

The Reason for Row Rules

As the senior researchers examined the data--already collected by columns--it soon became quite evident that columns did not have the same generalized significance for the fracture study that they had for the corrosion study. This is not to say that there were no fracture-relevant industry technologies. But it does say that such technologies were less numerous and that certain very important fracture-related adjustments were more product-specific than technology-specific.

Sector 7A01 (Iron and Carbon Steel) provides examples of both kinds of adjustments. In the real world technology (A) matrix, this sector employs both casting and forging to shape its output for use by other sectors. If fracture strength is an important metallic requirement, forging will be chosen over casting as the method of shaping steel. In World II, however, the metal characteristics will be the same, regardless of which shaping process is chosen, and casting is a less expensive process than forging. Therefore, in

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* The adoption of changed procedures and the emphasis on row-rules should not be misconstrued as an "internalizing" of the data-collection process, i.e., a deviation from the "industry expert" concept which is inherent in the ex ante approach. Each of the permanent and ad hoc members of the project team is closely identified with one or more industries and is intimately aware of both industrial processes and industrial perspectives. Given the technological basis of Battelle's I/O model, and the research implications, the use of Battelle staff is seen to enhance the outputs of this project.

going from World I to World II conditions, changes would be incorporated into column 7A01 to indicate the choice of casting over forging, with significant savings in resource use. This is a column-specific adjustment.

The use of iron and steel as a material input is shown across row 7A01. Regardless of what happens to the technology of producing steel, its physical characteristics also change from World I to World II. As has already been discussed, we hypothesize that in World II all steel will have the strength and other fracture-relevant qualities now found only at the upper end of the quality distributions; and we would know exactly what those characteristics were and how to design with them to achieve functional requirements. This has been calculated to imply that, in general, each user of steel as a material could expect to achieve with 51 pounds of steel the same functional performance vis-a-vis fracture that calls for 100 pounds of steel in World I.* Thus, in going from World I to World II, all else being the same, we would reduce the coefficients on the row 7A01 to 51 percent of what they were in World I. This is a row-specific adjustment.

In writing a material row rule for row 7A01, however, we must keep clearly in mind that fracture strength is not the only characteristic for which the designer uses steel. There are several factors that immediately come to mind:

- Porosity: There are many uses (e.g., containers for gases) in which the strength requirements can be met, even in World I, with less metal than is used. However, in order to achieve gas-tight walls with economical fabrication methods, the walls are made thicker.

- Stiffness: In many instances (table tops, bridge decks) a strong, thin sheet will resist fracture admirably. However, in order to prevent sagging (i.e., to achieve the requisite degree of stiffness), more and thicker material would have to be used.

- Weight/balance: There are uses (e.g., golf clubs) in which weight and balance, rather than strength, are the critical criteria. In such cases, regardless of fracture relationships, a given amount of material would be needed--perhaps the same amount in World II as in World I.

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* The 49 percent reduction in steel used in this example is, to be sure, more than an arbitrary figure. While the details of the row rules will be found in Appendix D, we note that first principle calculations suggest that World II metals may be reduced to 51 percent of their World I thicknesses. Similarly, most metals may be reduced to 81 percent of their World I thicknesses for application in World III. This convention is referred to as the "49/19 Rule", representing the percentages by which many metal thicknesses may be reduced in Worlds II and III, respectively.

Implicitly, therefore, any row rule may be subject to exceptions.* It has been found, however, that the use of row rules and closely similar devices introduced many efficiencies into these simulations.

The Nature of the Row Rules

Generalized rules, intended primarily to be applied across the rows, have been established for a variety of relationships.** It must be emphasized at this point that it would be possible to treat these relationships as applicable generally by the row, but with column exceptions, or as cell adjustments in specified blocks of columns that affect only certain rows.

Some of these rules fall into groups, one of which has been termed "materials" rules and another "M/R", or "maintenance and repair" rules. There is also a miscellaneous group made up of rules concerning "fracture-related research and development", "fracture-related environmental cleanup", "transportation cost reductions" because of material weight adjustments, and "inspection".

At this point in the text, the row rules will be discussed in general terms: the considerations that went into their establishment and the limitations that affected them. The particular rules, the numerical adjustments that they required, and the sectors to which they applied are set forth in Appendix D.

The Materials Rules involve adjustments in material inputs because of technologies that would apply to World II and/or World III. Each applies to a different material or group of materials. There is a general "49/19" rule that applies to all metals; exceptions to this rule--and there are many--result from the fact that, in many uses of metal, there are characteristics other than fracture strength that determine design. Different rules (with different exceptions) have been established for wood, for ceramics and concrete, and for plastics and their composites. Rules were not established for paper, cardboard, and textiles because it is felt that fracture-strength is not the determinant of their thickness in use.

The M/R Rules are needed because of a convention that has been applied (with few exceptions) to the fracture model. This is that the sectors

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* Although the 49/19 rule, mentioned above in connection with steel, has also been applied to other metals, the exceptions mentioned for steel would not necessarily apply. For instance, electrical conductivity would be an important determinant affecting the use of copper, aluminum, etc.; and thermal conductivity or appearance might apply in other instances.

** Two rules that are not intended for row-wise application will also be discussed at this point. They are the scrappage rule and the down-time rule. Although actually applied by the column, these two rules are similar in many respects to the true row rules.

which produce specialized capital goods and sell them to capital using sectors (in the B matrix) also provide repair parts and services (in the A matrix and in final demand). It must be noted, however, that maintenance and repair parts/services may not be all that a given capital-producing row sector sells in the A matrix. Other legitimate A matrix transactions involve the sale of components (e.g., small electric motors for complex machines) or of supplies (the sale of cutting tools by the metalworking machine industry). Thus, in any given A-matrix cell on a capital-producing row, only part of the coefficient may represent M/R activity; only part of the M/R activity may involve fracture (the remainder involving corrosion, wear, modernization, cosmetic activity, etc.); and only part of the fracture-related M/R may be within project scope.*

Still other applications of the M/R rules within the A matrix derive from the definitions of the construction sectors. The bulk of construction activity consists of new construction, by definition delivered to the ultimate buyer only in the B matrix (for industrial construction) or in the final demand vectors (for residential or governmental construction). Maintenance and repair construction on industry account is delivered by the same construction sectors in the A matrix or in final demands. Like other capital producers, construction can also deliver components within the A matrix, often, but not always, to another construction sector (e.g., delivery of a bridge to railroad construction or a dam to public utility construction). Thus, in the A matrix, only part of the coefficient may involve M/R activity, only part of the M/R activity may be fracture-relevant, and only part of the fracture related M/R activity may be within project scope.

Finally, some part of total M/R services may be provided (also within the A matrix) by specially designated repair services (e.g., auto repair by sector 21.05 and other, miscellaneous kinds of repair by sector 21B04). But again, as in the cases discussed above, only part of the repairs may be fracture-related, and only part of the fracture-related repairs may be within scope.

The R&D and Cleanup Rules. The two special rows (20A05, Fracture-Related R&D; and 20C05, Environmental Cleanup) were established for the purpose of providing convenient row-wise adjustments in Worlds II and III. One of those sectors (20A05) has been defined so that it would have nothing to deliver in World II. This is to say that the output of this sector is defined within project scope. Any R&D, including fracture considerations, that would go on in World II is included as part of 20B05 (All Other R&D). The Environmental Cleanup sector has been defined to include only those kinds of activity involved with spills of hazardous or environment-degrading substances. It is not directed toward old pollution, deliberate dumps, and the like.

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* It will be recalled that fracture "within scope" or "within design" refers to fractures or deformations not caused by human error or accident, vandalism, natural disaster, etc.

In World II, deliveries of fracture R&D go to zero; but in World III they are the same as in World I. Environmental Cleanup, however, would still continue in World II, since some spills occur for reasons that are outside of project scope. Since most of the cleanup in any "World" will result from the same kinds of events that have been separately examined in the Supplementary Models, the World II and III adjustments have been established with reference to Supplemental Model results.

The Transportation Cost Rules. Under I/O convention, transportation costs are paid by the purchaser, not by the seller/shipper. These costs are affected in two ways by fracture considerations. The only costs paid directly by the buyer relate to the weight or bulk of the goods purchased and transported. We have assumed that transport costs of all goods affected by the material rules are solely weight-related, not cube-related.

In the coefficient (A matrix) sense, only those inputs which change per dollar's worth of output can affect the transportation costs. For instance, if it takes a given amount of iron ore to make a unit amount of steel, the transport costs associated with ore will not change in the steel column of the A matrix, but if the amount of steel in an automobile declines by 49%, the transportation costs associated with steel will decline by the same proportion in the automobile column. Thus, in each column sector affected by material row changes, the relevant transportation coefficients have been reduced by an estimated proportion. This proportion is the weighted average of the materials reductions, implicitly assuming that all the materials share an average mass. It is felt that this assumption does not introduce significant error.

In this connection, it should also be noted that any hardware with reduced weights per unit will also reduce corresponding transport costs in both the B matrix and the final demand vectors. These reductions have been calculated as the coefficent-weighted averages of the transport reductions in the sectors producing the hardware items.

Also, in connection with transport costs, it should be pointed out that still another set of reductions must be calculated. The reductions in transportation coefficients, as a result of inversion, reduce the demands for activity by the transportation sectors. However, these sectors (as columns) are also affected by the materials rules. Implicitly, as we apply the materials rules, we not only reduce the weights transported (as discussed above), we also reduce the dead weights of the trucks, trains, boats and aircraft which do the transporting. If we assume no cube limitations, there is no change in fuel requirements per item transported; however, there is a reduction in the fuel costs of moving the transportation equipment/vehicles, whether full or empty. Coefficient changes for these latter fuel reductions have been made in the relevant transport sector columns of the A matrix.

The Inspection Rule. Almost without exception, every sector has something to inspect. It at least inspects its own capital periodically; it may inspect material inputs received from other sectors; and, if it produces any goods (as distinguished from services), it probably inspects work in process and finished outputs.

The process of inspection always involves persons (either part of labor costs in Value Added or purchased as a service from the outside), and it may also involve the use of capital equipment. As was true of other row activities, inspection may be undertaken for many reasons, only part of which can be considered to be fracture-related and within project scope. Where inspection involves the use of own labor (i.e., part of Value Added) or other special purchases in the A matrix, it has not been treated as a row rule, but has been treated as part of the column-specific adjustment.

Adjustments for Scrappage. One of the most nearly ubiquitous elements of fracture cost is scrappage, the loss of product during manufacture. Some scrappage occurs because imperfect intermediate inputs (such as glass containers for beverages) break in process; some occurs because of shortcomings of the product itself, which may or may not be fracture-related; and some occurs because of carelessness or accidents during manufacture.

When these accidents or imperfections occur or are discovered, affected goods-in-process often may be recycled or reclaimed, rather than discarded. For instance, in the manufacture of glass containers, broken bottles can be remelted and remolded. However, if bottles break while being filled in the beverage sector, the product (the beverage) is lost and the broken bottle probably will be scrapped, whether or not it is ultimately reclaimed. It is obvious that the precise stage of manufacture at which breakage occurs or an imperfection is discovered significantly affects the amount of the associated loss. For instance, any imperfect bricks that are discovered before they are fired can be recycled; after firing, they are usually discarded. When something is recycled, only the energy and labor expended on it is lost--but when it is thrown out, materials are lost as well.

Resources did not permit the calculation of scrappage at each stage of production. Even if they had, it would not have been possible to calculate scrappage rates from available industry data. Many of the reasons for scrappage are not fracture-relevant; and many fracture-related scrappages fall outside the scope of this study. A major cause of scrappage losses by fracture involve accidental breakage: a crate of bottles falls off a truck; a worker knocks over a stack of filled cartons. As neither of these is "fracture within design", neither should affect the scrappage rate.

For each sector, viewed as a column, the scrappage rate is taken as an average phenomenon that will affect all inputs by the same proportion. Once the actual rate is determined, the correction is quite simple. All A and B matrix coefficients in the affected sector's column are multiplied by (1-s), where "s" is the scrappage rate. This procedure reduces all inputs per unit of output (including the overall capital-to-output ratio) by the average proportion that would be saved through the elimination or reduction of scrappage within project scope.

Adjustments for "Downtime". In this study, the base period for which the cost of fracture is estimated is the calendar year 1978, after adjustment to peacetime, full employment conditions. Implicitly, under full employment, there will be no surplus capital in World I, so that any production loss because of shut-down must be made up in some manner. In this study it has been assumed that downtime can be made up by overtime in any sector which normally operates on a one-shift or two-shift workday. There are, however, some sectors which typically operate around the clock, such as blast furnaces, continuous chemicals processes, utilities, and petroleum refineries. These industries lose output during downtime and have no opportunity to recover. In order to maintain output, they must (in World I) hold in readiness standby equipment, some of which will be redundant in Worlds II or III.

The presence of standby capital, however, is not necessarily fracture-related within project scope. For this reason, the estimate of downtime-related redundancy must be corrected for both nonfracture downtime (maintenance for corrosion, wear, etc., or breakdown caused by nonfracture events) and for fracture beyond designed strength. After the downtime redundancy rate is estimated as a fraction of total capital, it is applied (to the B matrix, only) in a manner similar to that for scrappage.

The Process of Matrix Adjustments

In order to incorporate the changes from World I conditions to those of Worlds II and III, it was necessary to actually translate the above discussed generalizations into changes in coefficients. At this point we take up the procedure by which this was accomplished in terms of matrices, rather than of rules.

Changes in the A Matrix

As has already been indicated, data takers, operating sector-by-sector, collected industrial information mostly involving the technological aspects thereof. The bulk of this information was applicable to the A matrix --i.e., related to process changes which might occur under World II and III conditions. This material was reviewed at least twice (first by the data-collectors and senior economists, and then by the economists and the senior scientists of the project team) and incorporated as column-specific changes for 60 sectors in the A matrix.

At the same time this work was underway, the senior group, assisted by a very experienced industrial engineer, was establishing the row rules (see above). Where relevant, these rules were also incorporated into the column-specific changes in addition to any other changes that had been made.

Finally, the other (some 90) sectors were also adjusted for the row-wise changes embodied in the rules. Both sets of changes were carried out for World II and World III. It should also be noted in this connection that the scrappage rules were generally applied to the A matrix of World I before any of the other changes were made.

Changes in the B Matrix

Utilizing the data already generated for the separately researched sectors, the senior project staff determined the necessary changes in sector capital/output ratios implied by changes in technology. At the same time, all sectors were examined in terms of downtime considerations (see above). Every column sector in the B matrix was then adjusted for the combined impacts of the scrappage and downtime-redundancy rules.

In this connection, it should be noted that there were no formal or pervasive capital-related row rules*. Therefore, after the general scrappage/redundancy adjustments had been made, only the column specific adjustments called for by technological considerations needed to be made.

Changes in the U and R Matrices

In this context, the fracture study differs significantly from the earlier corrosion study and from the situation with respect to wear. These last two processes continuously remove from capital items materials that cannot be replaced easily by maintenance and repair or offset by capital redundancies. In the case of fracture processes, while the weakening may be progressive, it is also localized and therefore can be discovered by inspection and eliminated by parts-substitution in the M/R procedure. It appears, therefore, that there are no specific changes that should be made in the (Useful Life) U matrix in going from World I to Worlds II and III. What otherwise would be the fracture-relevant changes in useful lives generally are taken care of by overdesign, maintenance and repair, etc. To then adjust useful lives probably would significantly overstate fracture costs. There is, however, some minor shortening of useful life that still must be taken into account, even though it is too small to be handled by whole-year change in the lower limit of the useful life range. We propose that this be accomplished by changes in the R matrix.

The R (Replacement Rate) matrix is calculated cell-by-cell as a function of the U (Useful Life) and G (Growth) matrix values. By definition of the entire simulation situation, the G matrix does not change between "Worlds". Moreover, it has already been indicated that discrete year changes in useful lives would overadjust for fracture-relatedness between World I and Worlds II or III. This leaves only the replacement rates themselves as a vehicle for changes of proper proportions. Therefore the R matrix for World I has been calculated and changes have been made directly in it as the means of

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* Less formalized adjustments were made, however, to account for reduced needs, for example, for equipment held in capital and used in inspection. In addition, some small adjustments were made to account for those components of capital equipment which serve to protect against operation beyond design limits. Were it not for such "warning" devices, World II fracture (out of scope) could occur.

simulating World II and III situations. Since these R values are continuous functions, they can be adjusted by small increments so as to treat all sectors in a more consistently equitable fashion. As will be shown in Appendix D, the adjustments in replacement rates have been related to maintenance and repair activities.

Changes in Final Demand

With the exception of the capital formation final demand column, which is treated separately, other fracture relevant final demand changes summarized below include:

(1) fewer noncapital purchases/replacements associated with less fracture within scope.

(2) maintenance/repair activities associated with consumer and social capital.

(3) replacement rate changes associated with consumer and social capital.

(4) trade and transport margins associated with (1-3) above.

(5) Federal, state, and local payroll implications of fracture relevant inspection.

(6) capital redundancy issues.

Details of these changes are presented in Appendix D.

(1) Fewer noncapital purchases: accounted for here are those items of which less would be purchased as replacements due to less fracture within scope. Affected sectors include:

3A01	3B01	5A06
5.09	5X10	5.12
6A01	6B01	PB14
PC15	6D01	6C03
	8.07	

Examples of considerations in (1) include container breakage and loss of contents due to e.g., bags breaking, thermal shock breakage of china/crystal in dishwashers, and use of adhesives for do-it-yourself repair of a variety of broken objects or their application as preventive measures. The rules for each of the above are applied to PCE and the three government final demand columns.

(2) Maintenance/repair activities: considerations taken account of here include application of the five maintenance/repair rules

derived for A-matrix changes to the noncapital shares of the final demands for all consumer and social capital producing sectors. For example, PCE final demand for Sector 9.01, Engines and Turbines (almost all of which consists of outboard motors in PCE), is $288 million. Of this amount, 7.4 percent ($21 million) consists of parts and factory authorized repairs (including labor). Of the $21 million, Rule #3 is applied, i.e., one percent of the $21 million is considered the fracture relevant portion, thus $210,000 less Sector 9.01 parts and repair services are purchased by PCE in World II.

Adjustments similar to the above are applied to the noncapital shares of final demand for all of the other social and consumer capital producing sectors. For noncapital producing sectors, rules #1, #2, and #5 are applied to each of the final demands where, for example, fracture relevant maintenance and repair services are provided by Sector 19.01 (Construction, Residences), Sector 21B04 (Repair Services Except Auto), and Sector 21.05 (Automobile Repair and Services).

(3) Replacement rate changes: as discussed in Appendix D, fracture relevant replacement adjustments have been applied to all appropriate consumer and social capital stocks.

(4) Trade and transport margins: account is taken here of trade and transport margins associated with adjustments in (1-3) above, and, most important, for overall transport savings due to lighter weight materials being delivered to final demand. In (1), trade and transport margins associated with fewer purchases of noncapital items were calculated. In (2), as trade and transport margins are already included in the costs of repairs, no additional changes are made. In (3), margin adjustments which account for fewer replacements were applied. For transport savings which result from delivery of lighter weight products to final demand, a set of rules, similar to those for the A-matrix transport changes, were formulated and applied. Generally, these rules accounted for lighter weight "hardware" going into the production of consumer and social capital for all capital producing sectors (8.01 through 16B02).

(5) Government payrolls associated with inspection: here, estimates of within-scope, fracture-relevant inspection activities undertaken by Federal, state, and local governments were calculated and applied as payroll savings in each of the government final demands. Total savings for World II were estiamted at $175 million; total additional costs in World III were estimated as $175.9 million. These figures reflect payrolls associated with fulltime job equivalents but do not include, for example, armed forces personnel who inspect military aircraft for fracture within scope. If not engaged in inspection activities, such personnel would be assigned other duties.

(6) Capital redundancy: the only capital redundancy identified in final demand was for Sector 11.02 (Aircraft and Parts), in the Federal government (defense) column. After allowances for corrosion, wear, and fracture beyond scope, it was estimated that 3 percent of the total defense aircraft fleet is inoperative because of fracture within scope.

Technological Changes in the Column Specific Sectors

As a result of interviews with firms in the relevant industries and discussions among the senior scientists, column-specific technological changes were quantified for a group of some 60 sectors. These sectors were the ones for which the row rules were not sufficient to reflect the changes required in Worlds II and III. In going from the real world (World I) situation to the two hypothetical situations (Worlds II and III), specific technological changes took place in these sectors that required column-specific changes in their direct technical coefficients. At this point, the natures of these changes and the row inputs that were affected will be set forth briefly. The more generalized adjustments, which these sectors shared with the other 90 sectors, will be discussed later.

Sector 1.01, Livestock and Livestock Products
Sector 1A03, Forestry Products
Sector 7C01, Stainless Steel
Sector 8.01, Metal Cans
Sector 8.02, Metal Barrels, Drums and Pails
Sector 19A03, Construction, Railroad
Sector 19C03, Construction, Other Public Utility
Sector 19D04, Construction, All Other Construction
Sector 20.01, Wholesale and Retail Trade

For these nine sectors, no specific technological changes had to be made other than the changes in Value Added (VA) because of inspection (of capital, of inputs, and/or of outputs). For each sector, the proportion of the VA coefficient that was labor cost differed, as did the proportion of labor cost that was involved in inspection. Therefore, inspection adjustments could not be treated as a row rule.

In Sectors 1.01, 1A03, 19D04, and 20.01, inspection costs would be reduced slightly in World II and even less in World III, as compared with World I. In the other five sectors, while World II would have reduced inspection, World III was judged to require an increase in inspection costs because the real world level of inspection fell below that required by best practices.

Sector 1B03, Fishing, Hunting and Trapping

This sector was found to require fewer ropes and nets, especially the former (from 3807, Miscellaneous Textiles), in the no-fracture world

(World II) than in the real world. Because of the importance of rope (for net repair as well as for various load-handling purposes), best practices (World III) would require the use of more rather than less. Inspection of boat and gear would be reduced somewhat in World II and by less in World III.

Sector 2A04, Underground Coal Mining

The most important fracture related changes in this sector involve roof bolts (from 8.07, Other Fabricated Metal Products) along with the labor (VA) to inspect the roof and to install the roof bolts. In both cases, inputs in World II would be lower than real world practices. However, in order to achieve current best practices, both should be increased significantly.

Sector 2A05, Crude Petroleum
Sector 2B05, Natural Gas

The oil and gas well sectors (operating, but not drilling the wells) are faced with a special fracture problem--blowout under gas pressure--much of which is within the well design. Blowout preventers (from Sector 10.04, Oil Field Machinery) would be used distinctly less in World II and slightly less in World III. Similarly, environmental cleanup services (from 20C05) would also be reduced from World I levels, as would inspection labor (VA).

Sector 2.06, Stone and Clay Mining

Packaging materials used in handling the output of this sector come from sectors 4.07 (Pulp, Paper, and Paper Products except Containers), 4.08 (Paperboard Containers and Boxes), and PC15 (All Other Manufactured Plastic Products). These supplies would be generally reduced in the World II, but would be increased over real world levels in World III. Much the same can be said about the tires (from P.13) used on off-the-road vehicles. Conveyer belts (from PA14) are subject to more breakage in the real world than in either of the other two situations. Similar reductions in inspection labor would be found in both hypothetical worlds.

Sector 3X05, Fabrics, Yarns, Threads, and Soft Floor Coverings

Inputs of natural fibers (from 1.01 and 1.02) and manmade fibers (from P.08) are higher in the real world than in World II. However, to achieve best practices, these inputs should be increased. Current inspection labor levels are thought to be at the best practice level, but they would decline in a no-fracture situation.

Sector 3A07, Metal Tire Cord

The general application of the materials rules to this sector implies special technological changes because the same lengths of wire would have to be used. This means that the wire would be drawn to smaller diameters in both Worlds II and III than in World I, with World II diameters smaller than those of World III. To accomplish this would require more machinery and supply parts (from 10.07, Metalworking Machinery), more electrical energy (from 18.02), more water (from 18.04), and more labor (from VA). The reductions in diameter would also reduce the use of plating chemicals (from 5.03 and 5B06), the use of lime as a lubricant (from 6.02), plating metals (from 7X04), and labor (from VA).

Annealing carried out solely for fracture prevention purposes would be eliminated in World II and left unchanged in World III. This would affect the use of special machinery and supplies (from 9.02), chemicals (from 5.03), electrical energy (from 18.02), gas (from 18.03), water for cleanup (from 18.04), insurance on the equipment (from 20XA2), and inspection labor (from VA).

The net effects of these changes are very substantial <u>increases</u> of World II use of inputs from Sectors 10.07, 18.04 and VA; total <u>elimination</u> of gas and very substantial reductions in the use of equipment/supplies from 9.02 in World II; and World III increases in inputs from 10.07, the energy sectors and VA.

<u>Sector 4.01, Sawmills and Planing Mills</u>

Aside from inspection labor, which would be reduced in World II and increased in World III (primarily in terms of timber inputs and lumber outputs), there is only one other column-specific change in this sector. In World II there would be a significant reduction in the breakage of saw blades (from Sector 8.07, Other Fabricated Metal Products), with a lesser reduction in World III.

<u>Sector 4.02, Veneer, Plywood, and Laminated Wood</u>

In this sector, inspection would be reduced in Worlds II and III.* The only other technological adjustments would involve inputs from Sectors 4.03 (the lumbering component) and 5A06 (Adhesives). In Worlds II and III, log inputs would be reduced via reductions in splitting and buckling; and adhesive inputs, for reasons of ply delaminations, would be reduced in World II. Best practice, however, would require increased use of adhesives.

<u>Sector 4.03, All Other Lumber and Wood Products, Except Containers</u>

Aside from inspection, reduced in both Worlds II and III, only adhesives (Sector 5A06) would be affected by specific technological change. Although there would be no World II reduction in adhesives--it being thought

* Unless otherwise specified, hereafter, "reductions in Worlds II and III" will always imply larger reductions in World II than in World III.

that the minimal amount possible is now used--more should be used in World III.

Sector 4XA5, Wooden Furniture and Fixtures

Again, inspection and adhesives are the only column-specific inputs changed. Inspection would be reduced in both Worlds II and III. Adhesives (from Sector 5A06) would be reduced in World II and increased significantly in World III.

Sector 5.01, Petroleum Refining and Related Products

This sector only refines crude petroleum; it neither operates the wells nor transports and sells the products. The only specific fracture-relevant changes in technology involve inspection labor, the purchase of ultrasonic inspection of refinery equipment services (from Sector 20D05), and the purchase of cleanup services after spills (from 20C05). Cleanup services would be reduced in both Worlds II and III; ultrasonic inspection would be eliminated in World II and substantially reduced in World III. Inspection labor (from VA) would be reduced in both Worlds II and III.

In this connection, it should also be noted that labor for maintenance and repair is furnished by this sector, since it is a very substantial part of the operation. This input also is reduced in both Worlds II and III.

Sector P.07, Plastic Materials, Resins and Synthetic Rubber

This sector provides materials only, no formed or extruded products. In addition to inspection (only of equipment) that is reduced in both Worlds II and III, the only specific technological changes involve inputs from Sector 5.03 (Industrial Inorganic and Organic Chemicals). This sector provides plasticizers, use of which is required to prevent brittle fracture. These inputs would be reduced in World II, increased in World III.

Sector P.08, Organic Manmade Fibers

This sector is affected essentially in the same ways as P.07, above.

Sector P.13, Tires and Inner Tubes

In terms of fracture-related technology changes, this is one of the more stringently affected column sectors. There are three main aspects of fracture impacts: the substitution of natural for synthetic rubber, reinforcement against fatigue and brittle fracture, and the avoidance of delamination.

Natural rubber (produced in Sector 1A03, but imported into the U.S.) is far superior to synthetic rubber in terms of fracture resistance in Worlds I and III, but not in World II. Thus, inputs from 1A03 would be unchanged in World II and significantly greater in World III. Synthetic rubber inputs (from Sector P.07) would not change in World II and would decline somewhat in World III.*

Reinforcements in terms of tire cord (nonmetallic from 3B07, metallic from 3A07) and the use of carbon black (from 5B06), both for the prevention of fatigue and brittle fracture, would be substantially reduced in World II; cord would be increased in World III, but carbon black is already at best practice levels. Adhesives (from 5A06) used to protect against delamination would be eliminated in World II and kept unchanged in World III. Breakage of industrial belting (from P.14) and inspection would be substantially reduced in World II and unchanged in World III.

Sector PB14, All Other Rubber Products

The bulk of manufactured rubber products--i.e., all except tires, tubes and industrial belting--are technically affected in a manner quite similar to tires and tubes. The substitution of natural for synthetic rubber affects inputs from 1A03 and P.07 in the same ways as was true in the case of P.13. Reinforcing (with fabric from 3X05, nonmetallic cord from 3B07, and carbon black from 5B06) would be reduced in World II and unchanged in World III, as would inspection labor.

Sector PA15, Plastic Pipe

In this sector, the use of chemical additives (from 5.03), quality control supplies (from 14A01) and inspection and quality control labor would all decline in World II and increase in World III.

Sector 6A01, Flat Glass

There are several significant fracture-related column changes in this sector (in addition to the ubiquitous row rules). Packaging, to reduce breakage in handling and transportation, would be reduced in World II and increased in World III. This would affect inputs from sectors 4.03 (excelsior from miscellaneous wood products), 4.04 (wooden containers), 4.07 (paper, except containers), 4.08 (cardboard containers), and PC15 (all other plastic products).

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* Application of the P.07 materials row rule would reduce this input in both Worlds II and III.

Chemical hardening would increase chemical uses (from 5.03) in World III, but would not occur at all in World II. Uses of energy (from electricity, 18.02, and gas, 18.03) for annealing would decline in World II, and be unchanged in World III. Inputs of refractories (Sector 6D03), replaced as a result of thermal shock, would be reduced in both Worlds II and III. Wire reinforcements for door and window glass would decline in World II and remain unchanged in World III. And the use of inspection labor (for equipment and outputs) would decline in both Worlds II and III.

Sector 6B01, Glass Containers

In many respects, this sector behaves in the same manner as 6A01, especially with respect to packaging, refractories, energy for annealing, and inspection labor. There are, however, some differences.

Plastic "overcoats" on glass containers require World I inputs from PC15. These would decline significantly in World II and increase somewhat in World III. Unlike flat glass, containers require special equipment and supplies for annealing and cooling from Sectors 9.02 (General Industrial Machinery and Equipment) and 10.08 (Special Industry Machinery), which are reduced in both Worlds II and III.

Sector 6C01, Auto and Truck Windshields

This sector occupies a position of special visibility because of its ability to complicate otherwise minor motor vehicle accidents. There are several column-specific changes from World I to World II and III conditions. Protective packaging from 4.04 and 4.08 (wood and cardboard containers) would be reduced in World II and kept unchanged in World III, as would annealing energy (gas from 18.03) and inspection. Lamination, requiring adhesives (from 5A06) and plastic sheeting (from PC15), would be greatly reduced in World II, but kept unchanged in World III.

Sector 6D01, All Other Glass Products

This sector behaves much like some of the other glass sectors, but not completely like any. With respect to packaging, annealing energy, annealing equipment, refractories, and inspection, it is like 6B01. However, 6B01 has several other adjustments that are not made in Sector 6D01.

Sector 6A03, Structural Clay Products, except Clay Refractories

This sector is affected by three fracture-related technologies that are not covered by row rules. These include considerations of porosity, packaging and inspection labor.

Porosity of the products is a function both of ingredients and firing temperatures. In World I, both are controlled because they directly affect fracture resistance. In World III, best practice would require increases; in World II, fracture would not occur and the inputs could be reduced. Firing temperatures directly affect energy inputs from coal mining (2A04, 2B04), petroleum refining (5.01), electricity (18.02), and gas (18.03). Ingredient additives would come from stone and clay mining (2.06) and chemicals (5.03). Packaging inputs, typically reduced in World II and increased in World III, come from sectors 4.03 (excelsior, etc.), 4.07 and 4.08 (paper and cardborad containers) and PC15 (plastic sheet). Inspection labor is reduced in both Worlds II and III.

Sector 6B03, Structural Concrete Products and Ready-mixed Concrete

Fracture-related technology changes include the use of chemical additives (from 5.03), these being reduced in World II and greatly increased in World III. In addition, inputs of reinforcing bars and wire (from 8C05) and inspection labor would be reduced in both Worlds II and III.

Sector 6C03, Pottery, Whiteware, and Porcelain Products

This sector is similar in some respects to 6A03. Additives to reduce porosity come from 2.06 (Stone and Clay Mining) and 5.03 (refined alumina, a chemical); both are reduced in Worlds II and III. Higher heats to reduce breakage involve both electricity (18.02) and gas (18.03), both down in World II and increased slightly in World III. Packaging (supplied by Sectors 4.03, 4.04, 4.07, 4.08, and PC15), which is very important in World I, would be reduced considerably in World II but raised in World III. Inspection, mainly of finished products, would be reduced in World II, and remain unchanged in World III.

Sector 6D03, Clay and Nonclay Refractories

Packaging and inspection are the only factors affected by other than row rule considerations. As above, packaging (from Sectors 4.03, 4.04, 4.07, 4.08, and PC15) is down in World II and up in World III. Inspection is reduced in both Worlds II and III.

Sector 7A01, Iron and Carbon Steel

This sector is subject to special adjustments, particularly in World III, that introduce an anomaly into World II/III relationships. In addition, there are several other sets of adjustments that further complicate the relationships.

In World III, the substitution of continuous casting for slabbing constitutes both a best practice--it reduces the proportion of trash- or slag-caused imperfections that must be cropped--and a source of process economies. There is no fracture-relevant reason to assume continuous casting in World II, since it is not present in World I and would not affect or be affected by World II metal characteristics (as would the castings-for-forgings substitution, below). Continuous casting would lead to significant World III savings in the use of coal (from 2A04, 2B04 and 2C04).

In Worlds I and III, the casting of steel shapes is technically feasible and economically desirable, but it results in a lower-quality product (in terms of fracture resistance) than does rolling or forging. In World II, castings would have the same metal characteristics as forgings or rolling-mill products and would be substituted because of cost economies. This would reduce the World II use of oil for heat (from 5.01) and would reduce the consumption of machine parts and supplies from 10.07 and 10.08 (Metalworking and Special Industry Machinery). Also, in Worlds I and III, annealing would be required that would be unnecessary in World II; this would lead to World II reductions in energy used (from oil, 5.01; electricity, 18.02; and particularly gas, 18.03).

The greater use of casting in World II would, however, increase the use of scrap instead of new metal, and would substantially increase the 7A01 diagonal in World II over that of World I or III.

In World II, compared to Worlds I and III, there would be considerably less spalling--or thermal shock degradation--of coke oven refractories (from 6D03).

Finally, inspection labor would be reduced in World II and increased in World III over World I levels.

7B01, Alloy Steel

In many respects, this sector behaves in a manner similar to Sector 7A01. This is especially true with regard to annealing and inspection. In the case of the castings-for-forgings substitution, there is impact on inputs from 10.07 and 10.08, but not from the energy sectors; and the increased use of scrap metal affects both 7A01 and 7B01 inputs.

7.03 Aluminum

As was the case for the iron and steel sectors, this also is affected by the World II castings/forging substitution, by reductions in World II annealing, and by changes in inspection labor.

The substitution of castings for forgings affects parts and supplies from 10.07. Annealing changes in World II reduces energy use (electricity and gas) and parts and supplies related to annealing ovens (from 9.02, General Industrial Machinery). Inspection labor is reduced in World II and increased in World III.

Sector 8.03, Metal Sanitary Ware and Plumbing Fittings

In this sector, enameling (from 8.07) can be reduced in World II because of no-fracture conditions. Inspection labor would be reduced in World II and increased in World III.

Sector 8.04, Nonelectric Heating Equipment
Sector 8A05, Structural Metal
Sector 8B05, Boiler Shop Products

In all these sectors, inspection labor would be reduced in World II and increased in World III. Rewelding after inspection would be reduced in both Worlds II and III, affecting inputs from 7A01 (welding rod), 18.02 (electricity) and the labor component of VA.

Also, in Sector 8B05, there would be another affected activity, the reglassing of tank interiors after inspection, which would reduce World II and III inputs from 5.03 (glass frits) and 18.03 (gas energy).

Sector 9.01, Engines and Turbines

Three fracture-related, column-specific, technological considerations affect this sector--heat tempering of metals, substitutions of less expensive for more expensive metals and alloys, and inspection labor. Tempering would be unnecessary in World II, but should be increased in World III. This would lead to reductions in World II use, and increases in World III use, of energy from oil (5.01), electricity (18.02) and gas (18.03). Metals/alloys substitutions would reduce World II and III inputs from iron and steel (7A01, 7B01) and all nonaluminum, nonferrous metals (7X04). Inspection labor would be reduced in World II, increased in World III.

Sector 9.02, General Industrial Machinery and Equipment

Only two fracture-related column-specific adjustments--substitution of welding for fastening and use of inspection labor--would affect this sector. In World II, welds would be of full strength and could replace other types of joining. This would reduce inputs from 8.06 (screw machine products and stampings) and would increase welding supplies (10.07) and energy (18.02) over those required in Worlds I and III. Inspection labor would be reduced in World II and increased in World III.

Sector 11.02, Aircraft and Parts

This sector is profoundly affected by column-specific technological adjustments. In addition to the metals materials rules (row rules), World II inputs of all metals are affected both by substitutions among metals and alloys, and by substitutions of castings for forgings. Since World I is assumed to be at best practice in these respects, Worlds I and III are the same for all metals*. In World II, however, iron and steel inputs (7A01) would rise substantially while alloy steels, aluminum and other nonferrous metals (7B01, 7C01, 7.03, 7X04) would decline substantially.

Shifts in fabrication methods, especially the substitution of welding for riveting would also affect only World II. Screw machine products and stampings (8.06) would be substantially reduced, as would metalworking supplies (10.07), the use of electricity (18.02) and gas (18.03), the use of water (18.04), and labor (VA). Inspection labor (VA) and x-ray supplies (12A07) would also decline but only in World II.

Sector 11.03, Ship and Boat Building and Repair

The main factors specifically affecting this sector are inspection and rewelding after inspection. Inspection would decline in World II and increase in World III; this affects fracture control instrumentation (parts/supplies from 14A07) and labor (VA). Rewelding after inspection would be reduced in both Worlds II and III, affecting inputs from 7A01 (welding rod), electric energy (18.02) and labor (VA).

Sector 14.04, Optical and Ophthalmic Goods

This sector is affected by the substitution of glass for plastics in lenses, the substitution of chemical for heat tempering of glass, and inspection. Weight reductions in glass via tempering and grinding to finer thicknesses (in both Worlds II and III) would lead to reduction in plastics (P.07) without increases in glass (6D01). Chemical tempering, in World III only--since tempering is unnecessary in World II--would increase the use of chemicals (from 5.03) but would not change energy use (from 18.02). Taken together, inspection and glass/plastic substitution would reduce labor inputs in both Worlds II and III.

Sector 17.01, Railroads and Related Services

This sector operates railroads. The three column-specific adjustments affecting it would involve fuel reductions through reduced rolling-stock weights, reduced environmental cleanup, and inspection of track and rolling stock.

Fuel consumption would be reduced in both Worlds II and III, affecting inputs of coal (2A04, 2B04), diesel fuel (5.01) and electricity

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* A combination of factors is responsible for the assumption that Sector 11.02 operates at best practice. In addition to the massive R&D investments that have been made, the overall quality of U.S.-made military and commercial aircraft is unsurpassed; the industry is heavily regulated and evaluated; and the consequences of failure are tragic and highly visible.

(18.02). Environmental cleanup caused by fracture related spills (20C05) would also be reduced in both Worlds II and III. Inspection labor would decline in World II, rise in World III.

Sector 17.02, Local and Other Highway Passenger Transport

Like 17.01, this sector is affected by weight reductions in rolling stock and by inspection labor reductions. Both reductions occur in Worlds II and III. Fuel reductions affect inputs from 5.01 (gasoline and diesel fuel) and 18.02 (electricty).

Sector 17.03, Motor Freight and Warehousing

Like other transportation sectors, this one will have World II and World III reductions in fuel, via rolling stock weight reductions, that affect gasoline/diesel fuel (5.01). Trucks, like railroads, are involved in fracture related spills of hazardous substances. Inputs from 20C05 (environmental cleanup) will be reduced in both Worlds II and III, as also will the use of inspection labor (from VA).

Sector 17.04, Water Transportation

Although this sector's capital is floating (rather than rolling) stock, fuel use is reduced in both Worlds II and III. Affected inputs are from coal (2A04, 2B04) and gasoline/diesel fuel (5.01). Environmental cleanup (20C05), mainly for oil spills, will be reduced in both Worlds II and III, as will inspection labor (VA).

Sector 17.05, Air Transport

Like the other transport sectors, this one will have World II and III reductions in both enviromental cleanup (20C05) and inspection labor (VA). Fuel savings (5.01) via weight reduction will occur, however, only in World II. In addition, there are several types of x-ray and other electrical inspection methods used by this sector, supplies and parts for which (from 12A07 and 12B07) will be reduced in World II, increased in World III. We note that reductions in x-ray equipment would affect only that part which is applied to the inspection of aircraft components. There would be no change in that portion of x-ray equipment used for viewing passenger baggage.

Sector 17.06, Pipelines

This transportation sector has no "rolling stock" and therefore no associated fuel savings. However, reductions in environmental cleanup (20C05) and inspection labor (VA) will occur in both Worlds II and III.

Sector 17.07, Transportation Services

This sector is only peripherally associated with the act of transporting. Only inspection labor, of all its column-specific inputs, is likely to be reduced, and that only in World II.

Sector 18.02, Electric Power

This sector has been judged to be less specifically affected by fracture than was originally assumed. In terms of its technology, some of the more socially concerned aspects (particularly nuclear generation) represent only a small part of total activity which, in any event, is subject more to corrosion than to fracture as a cause of failure. In general, the sector is close to best fracture control practice*. Aside from row-rules, there are only three adjustments to be made. In World II, but not III, there will be significant saving in the purchase of power from the grid (the 18.02 diagonal) to replace losses by fracture-caused failures. Some reductions in environmental cleanup (20C05) and inspection labor (VA) will occur in both Worlds II and III.

Sector 19.01, Construction, Residences

The main column specific technology changes in this sector involve concrete. In World III, but not World II, concrete should be better protected for a better cure. This would require increases in the use of straw (from 1.02), cloth (3X05) and/or plastic sheeting (PC15). Additionally, also only in World III, footing should be widened for better structural support, requiring more ready-mix (from 6B03).

Inspection labor (VA) should be reduced in World II and increased in World III; and reductions in many material inputs, via the row rules, would imply further reductions in labor to handle them in both Worlds II and III.

Sector 19.02, Construction, Nonresidential Buildings

Better World III curing of concrete would require protection by straw (1.02), cloth (3X05) and plastic sheet (PC15). The only other column specific change would be in inspection labor (VA), reduced in World II and increased in World III.

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* Comments similar to those which footnote Sector 11.02 (above) apply here, particularly as they relate to nuclear power generation.

Sector 19B03, Construction, Pipelines

Inspection and reweld after inspection are the two column-specific fracture related technology changes affecting this sector. The first reduces labor (VA) in World II and increases it in World III. The second leads to reductions in both Worlds II and III in welding rods (7A01), electrical energy (18.02) and labor (VA).

Sector 19A04, Construction, Highways

There are four column-specific changes that affect this sector. Covering concrete for better curing is unnecessary in World II, but requires additional World III inputs of straw (1.02), cloth (3X05) and plastic sheet (PC15). Improving roadbed drainage to reduce winter freeze-thaw fractures is also not required in World II, but calls for substantial increases in gravel (2.06) in World III. Inspection labor requirements would be reduced in World II and increased in World III; and the application of material row rules further reduces labor requirements for handling in both Worlds II and III.

Sector 19B04, Construction, Bridges

Most of the technology changes in this Sector come from the application of the row rules. There are two, however, which are column-specific. Inspection labor is reduced in World II and increased in World III. Protection (stone from Sector 2.06) of bridge abutments from collisions by boats and ships is unchanged in World II, but should be increased substantially to achieve best practice.

19C04, Construction, Dams

Additional covering for better concrete curing is needed in this sector in World III. In addition, inspection labor can be reduced in both Worlds II and III.

Sector 20A05, Fracture Related Research and Development

This sector has been defined in terms of R&D directed toward the understanding of that aspect of fracture which is within the scope of this project. All other fracture related R&D is treated as "other R&D" and placed in 20B05. Thus, by definition, this sector disappears from the A matrix in World II, while there are no changes in its technology between Worlds I and III.

V. I/O MODEL OUTPUT

After the changes were made in the A, B, R, and final demand matrices, the I/O model was run to obtain the transaction tables for the three fracture "Worlds". This chapter provides a summary of the kinds of information generated by the model, the uses to which it can be put, and the types of analysis that can be based upon it.

The Overall Procedure

It will be recalled from previous discussions that the I/O modelling activity has taken place in three distinct phases. First, a description of the economic processes characterizing the real world of 1978 was embodied in a national table of 150 sector detail; this version of the model we have called "World I". Second, the economic processes of the real world have been altered to show what they are expected to be in each of two hypothetical situations with respect to fracture: "World II", or the no-fracture base, described the 1978 processes expected to characterize an economy in which our artifacts behaved (with respect to fracture/deformation) exactly to the limits of their original design, and in which the materials from which they were made had precisely known and uniform characteristies, as detailed in Chapter II; "World III", or the best-practice world, described the 1978 processes expected to describe an economy in which everyone applied all of the best fracture control/prevention practices known in 1978.

Any differences found between Worlds II and I must, by definition, be ascribed to the total costs of fracture, these costs being incurred either in the form of excessive use of resources to avoid fracture or in the form of resources destroyed by fracture within design--i.e., the failure of artifacts to function vis-a-vis fracture as they were intended and designed to do. Any differences between Worlds III and I must, by definition, be ascribed to currently preventable or reducible costs of fracture in that they would not have been borne had everyone in the economy followed all current best practices. Any differences between Worlds II and III must, by definition, be ascribed to currently nonreducible costs of fracture in that current best practices cannot prevent these destructions or uses of resources.

Model Outputs: World I

In Appendix H of this report (separately bound), actual printouts are provided for the World I data bases and transactions tables. The format of these tables is uniform with those of the other "Worlds", so that each can be directly compared with all others. Sectors have been described, in terms of the products and processes involved in each, in Appendix C; and the terms used have both been discussed in previous chapters and more briefly defined in the Glossary (Appendix A). In summary, these outputs are described below.*

Data Bases

The data bases for this model consist of the A, B, G, U, and R matrices and the vector of noncapital final demands. Those for World I have been based on the Battelle-Columbus 127-sector I/O model for 1978 and have been disaggregated to the 150-order detail adopted for this study. In the process of disaggregating and checking these data, errors have been identified and corrected, and some revision and updating has been undertaken to better reflect 1978 real world state of the arts. Moreover, to whatever degree possible, the entire data base has been adjusted to reflect a peacetime, full employment level of resource use.

Of the World I material in Appendix H, the A (direct technology), B (capital to output), G (annual growth rate), and U (useful lives of capital) matrices and the noncapital final demand vectors are direct inputs into the model. The R (replacement rate for capital) matrix is calculated as a function of the G and U matrices. As will be shown, the A, B and R matrices and final demands must be adjusted between World I and Worlds II and III. The G matrix is the same for all three worlds; and the R matrix changes make interworld adjustments of useful lives unnecessary.

Calculated Outputs

There are two calculated outputs for World I shown in Appendix H, the so-called "modified dynamic inverse" and the dollar-flow or transactions table. The dynamic inverse shows the number of cent's worth of output required from each row sector to support one dollar's worth of final delivery by each column sector. The transaction table shows all the transactions in the economy as each sector purchases necessary inputs and sells its output to intermediate (industrial) and final users.

The Inverse. Under real world conditions of peacetime full employment, for instance, the iron and steel industry (7A01) has to supply 19 cent's worth of metal to support one dollar's worth of automobile/truck production (11.01) (see Table 3). This includes, in addition to the almost 9 cent's worth of iron and steel actually formed into the vehicle (Table 4), another 10 cent's worth of iron and steel going into everything that the motor vehicle industry buys from other sectors, plus that going into suppliers of those sectors, and their suppliers, ad **infinitum**. It is the power of the inverse that makes it possible for the I/O model to capture the indirect, as well as the direct costs of fracture.

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* Some exhibits will be shown in this chapter that illustrate material from the tables of Appendix H, for the benefit of those who do not have access to that volume. However, all such data will not be so supported.

WORLD I PAGE 20

DIRECT ANO INOIRECT EFFECTS, UNITEO STATES, DYNAMIC,1978

	10.04	10.05	10.06	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02	12802
6003 CLAY+NCLAY REFRACTORIES	.00659	.00620	.00732	.00415	.00554	.00842	.00199	.00370	.01203	.00322	.00138	.00514	.00584
6A04 ABRASIVES INC GRINO WH	.00116	.00150	.00180	.00619	.00332	.00472	.00498	.00631	.00188	.01653	.00106	.00859	.01034
6804 OTHER NONMET MINERAL PRO	.00099	.00109	.00129	.00327	.00197	.00340	.00451	.00564	.00154	.00827	.00071	.00576	.00355
7A01 IRON,CARBN STEEL+COKE	.15185	.13913	.16591	.08943	.11910	.18840	.02432	.07688	.27808	.06650	.01978	.10061	.11109
7801 ALLOY STEEL	.00589	.00582	.00682	.00366	.00636	.00747	.01110	.00348	.01122	.00247	.00160	.01041	.01649
7C01 STAINLESS STEEL	.00176	.00180	.00207	.00182	.01086	.00287	.00156	.00172	.00312	.00149	.00577	.00058	.00063
7.03 PRIMARY ALUMINUM	.00637	.01155	.01306	.C1061	.01737	.03204	.01373	.01674	.02151	.05344	.01367	.02317	.02322
7X04 OTHER NONFEROUS METALS	.01118	.01607	.01906	.02205	.02709	.02307	.04939	.03184	.01610	.01391	.01735	.06539	.06886
8.01 METAL CANS	.00020	.00023	.00021	.00028	.00021	.00028	.00020	.00028	.00035	.00041	.00025	.00040	.00044
8.02 METAL BARRELS,ORUM+PAILS	.00020	.00027	.C0023	.00016	.00026	.00038	.00023	.00065	.00038	.00038	.00029	.00036	.00042
8.03 MET SANIT+PLUMBING PRO	.00017	.00022	.00021	.00022	.00023	.00024	.00015	.00044	.00050	.00770	.00026	.00019	.00020
8.04 NONELEC HEATING EQUIP	.00040	.00057	.00052	.00052	.00268	.00060	.00038	.00747	.00053	.01582	.00058	.00047	.00049
...AL METAL	.00149	.00240	.00192	.00197	.00622	.00212	.00140	.02217	.00209	.00261	.00202	.00177	.00182
... PRO	.00102	.00188	.00117	.00146	.01360	.00139	.00085	.00825	.00139	.00294	.00116	.00112	.00119
...CTRL PRO	.00291	.00429	.00352	.00377	.01480	.00420	.00241	.01019	.00415	.01720	.00385	.00323	.00336
...RNGS	...126	.00798	.03092	.00893	.00664	.05614	.02682	.00507	.00878	.01140	.02855	.01242	.01526
		.01419	.00551	.00669	.02255	.03096	.01509	.04150	.01011	.02502	.00890	.00781	.00938
		...00190	.04626	.00108	.00138	.00601	.00118	.05333	.02814	.00141	.00088	.00240	.00204
				.02851	.04791	.02072	.01490	.02586	.01706	.01127	.00593	.02772	.03518
					...0372	.02481	.01479	.01092	.00361	.00177	.00059	.00105	.00095
						.00015	.00010	.00013	.00012	.00026	.00012	.00020	.00021
						...00260	.00124	.01182	.00311	.00166	.00125	.00207	.00219
							...67	.00091	.00221	.00079	.00041	.00122	.00132
								.00021	.00027	.00020	.00014	.00018	.00018
										.00561	.00404	.00405	.00433
										...00131	.00051	.00059	.00072
											.01640	.02823	.03035
												...0304	.00343
													.00761
18.0...													
18.04 ...													
19.01 NEW ...NONR...													
19.02 CONST,NONRESIO B...													
19A03 CONST,RAILROAOS													
19803 CONST, PIPELINES	.0000...												
19C03 OTHER PU, CONST	.00347												
19A04 CONST,HIGHWAYS	.00028	.0...											
19804 CONST,BRIOGES	.00001	.00001	.00001										
19C04 CONST, OAMS	.00001	.C0001	.00001	.00...									
19004 CONST, ALL OTHER	.00071	.00059	.00074	.0006...									
20.01 WHOLESALE+RETAIL TRAOE	.02375	.01758	.04492	.03110	.03250	.02...							
20XA2 INSURANCE	.00200	.00373	.00429	.00315	.00321	.0047...							
20X82 FINANC,REAL EST+AOVERTSG	.02454	.02796	.04606	.03326	.03493	.03284	...	.0273...					
20A05 FRACT RESEAR+OEVEL	.00063	.00105	.00123	.C0043	.00059	.00090	.00336	.00069					
20805 OTHER RESEARCH + DEVEL	.01802	.05227	.04303	.C2078	.02847	.04266	.04784	.02406	.01...				
20C05 ENVIRONMENTAL CLEANUP	.00021	.00018	.00024	.00018	.00025	.00024	.00018	.00026	.00033	...0024			
20005 OTHR BUSNS+PROFESNL SERV	.01250	.01145	.01232	.01080	.01582	.01056	.01129	.01586	.01028	.01271	.01...		
20.06 BUS TRAVEL,ENTER+GIFTS	.01312	.01127	.01450	.01458	.01356	.00855	.01473	.01094	.01385	.02583	.0192...		
21.01 PRINTING + PUBLISHING	.00208	.00324	.00346	.00204	.00266	.00278	.00486	.00338	.00234	.00250	.01236	.00299	
21.02 RAOIO + TV BROAOCASTING	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.000...
21.03 HOTELS + LOOGING PLACES	.00134	.00126	.00151	.00151	.00141	.00090	.00152	.00127	.00158	.00266	.00203	.00841	.00917
21A04 PERSONAL SERVICES	.00007	.C0009	.00012	.00065	.00035	.00014	.00011	.00011	.00012	.00012	.00061	.00026	.00027
21804 REPAIR SERV, EXC AUTO	.00097	.00040	.00058	.00079	.00054	.00040	.00028	.00340	.00036	.00064	.00084	.00140	.00143
21.05 AUTOMOBILE REPAIR+SERVC	.00238	.00326	.00416	.00221	.00229	.02990	.00209	.00347	.00333	.00362	.00307	.00313	.00328
21.06 AMUSEMENTS	.00038	.00028	.00037	.00039	.00034	.00023	.00037	.00031	.00038	.00065	.00050	.00093	.00101
21.07 MEOICAL + HEALTH SERVICE	.00013	.00023	.00022	.C0014	.00017	.00022	.00041	.00021	.00031	.00043	.00032	.00056	.00070
21.08 EOUCAT SERVC+NONPROF ORG	.00226	.00248	.00255	.00194	.00261	.00172	.00279	.00231	.00185	.00184	.00323	.00257	.00274
22.01 POST OFFICE	.00201	.C0276	.00335	.00190	.00345	.00211	.00320	.00239	.00241	.00218	.00405	.00406	.00480
TOTAL	1.78185	1.88387	1.94370	1.67514	1.88383	2.50014	1.98617	1.94649	2.25853	2.00663	1.71890	1.86220	1.91883

TABLE 3. DIRECT AND INDIRECT EFFECTS, WORLD I

FRACTURE WORLD I PAGE 20

DIRECT TECHNICAL COEFFICIENTS, UNITED STATES 1973

	10.04	10.05	10.06	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02	12802
6003 CLAY+NCLAY REFRACTORIES	0.00000	0.00000	0.00000	0.00000	.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6A04 ABRASIVES INC GRIND WH	.00010	0.00000	0.00000	.00453	.00158	.00173	.00281	.00404	0.00000	.01308	0.00000	.00676	.00827
6804 OTHER NONMET MINERAL PRO	.00007	0.00000	0.00000	.00194	.00069	.00115	.00281	.00404	0.00000	.00561	0.00000	.00422	.00184
7A01 IRON,CARBN STEEL+COKE	.09509	.08513	.10720	.05602	.06730	.08562	.00086	.03062	.16710	.02942	.00026	.06377	.06895
7801 ALLOY STEEL	.00400	.00358	.00451	.00236	.00396	.00361	.00729	.00129	.00704	.00124	.00053	.00845	.01379
7C01 STAINLESS STEEL	.00100	.00090	.00113	.00059	.00792	.00090	.00043	.00032	.00175	.00031	.00447	0.00000	0.00000
7.03 PRIMARY ALUMINUM	.00108	.00360	.00407	.00397	.00561	.01038	.00421	.00480	.00745	.02800	.00536	.01140	.01103
7X04 OTHER NONFEROUS METALS	.00263	.00403	.00554	.01061	.01247	.00480	.02651	.01639	.00024	.00279	.00558	.04477	.04689
8.01 METAL CANS	.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8.02 METAL BARRELS,DRUM+PAILS	.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8.03 MET SANIT+PLUMBING PRO	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.00024	.00022	.00697	0.00000	0.00000	0.00000
8.0[illegible] NONELEC HEATING EQUIP	0.00000	0.00000	0.00000	0.00000	.00193	0.00000	0.00000	.00681	0.00000	.01428	0.00000	0.00000	0.00000
[illegible]CTURAL METAL	0.00000	.00040	0.00000	.00012	.00381	0.00000	0.00000	.01998	.00001	.00078	0.00000	0.00000	0.00000
[illegible]SHOP PRO	0.00000	.00064	0.00000	.00039	.01143	0.00000	0.00000	.00666	.00003	.00155	0.00000	0.00000	0.00000
[illegible]RD	[illegible]	.00056	0.00000	.00027	.01016	0.00000	0.00000	.00666	.00004	.01318	0.00000	0.00000	0.00000
		.00536	.02766	.00638	.00424	.03653	.01855	.00143	.00476	.00670	.02273	.01014	.01287
		[illegible]	.00080	.00296	.01637	.01655	.00730	.03400	.00463	.01530	.00279	.00338	.00460
			[illegible]	0.00000	.00007	.00269	.00020	.04677	.01973	0.00000	0.00000	.00084	.00046
				[illegible]	.03716	.00865	.00798	.01770	.00737	.00467	.00115	.02112	.02758
					[illegible]	.01526	.00966	.00738	.00138	0.00000	.00006	.00017	.00009
					[illegible]	[illegible]	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
							0.00000	.00978	0.00000	0.00000	0.00000	0.00000	0.00000
							[illegible]	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19C[illegible]									[illegible]	0.00000	0.00000	0.00000	0.00000
19A04 [illegible]									.00184	.00054	0.00000	.00004	.00014
19804 CONST,BRI[illegible]									[illegible]	[illegible]	0.00000	.00008	.00018
19C04 CONST, OAMS											.00234	.01689	.01839
19D04 CONST, ALL OTHER											[illegible]	[illegible]	.00005
20.01 WHOLESALE+RETAIL TRADE	[illegible]												0.00000
20XA2 INSURANCE	.00023	[illegible]											[illegible]
20XB2 FINANC,REAL EST+ADVERTSG	.00965	.01215	[illegible]										
20A05 FRACT RESEAR+DEVEL	.00043	.00078	.00097										
20B05 OTHER RESEARCH + DEVEL	.01026	.03824	.03121	[illegible]									
20C05 ENVIRONMENTAL CLEANUP	0.00000	0.00000	0.00000	0.00000	[illegible]								
20D05 OTHR BUSNS+PROFESNL SERV	.00653	.00435	.00379	.00469	.00837	[illegible]							
20.06 BUS TRAVEL,ENTER+GIFTS	.00797	.00390	.00735	.00925	.00704	.00070							
21.01 PRINTING + PUBLISHING	.00008	0.00000	.00012	.00005	.00015	0.00000	[illegible]						
21.02 RADIO + TV BROADCASTING	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	[illegible]	[illegible]					
21.03 HOTELS + LODGING PLACES	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000					
21A04 PERSONAL SERVICES	0.00000	0.00000	0.00000	.00052	.00023	.00004	0.00000	0.00000	0.00000	[illegible]			
21B04 REPAIR SERV, EXC AUTO	.00067	.00014	.00026	.00052	.00023	.00004	0.00000	.00292	0.00000	[illegible]			
21.05 AUTOMOBILE REPAIR+SERVC	.00072	.00130	.00146	.00047	.00031	.01924	.00010	.00105	.00074	.00018	[illegible]		
21.06 AMUSEMENTS	.00004	0.00000	0.00000	.00002	0.00000	0.00000	0.00000	.00002	.00001	.00002	.00002	[illegible]	
21.07 MEDICAL + HEALTH SERVICE	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.00019	.00006	.00010	.00025	.00014	.00034	
21.08 EDUCAT SERVC+NONPROF ORG	.00134	.00131	.00136	.00100	.00149	.00034	.00128	.00116	.00066	.00058	.00190	.00127	[illegible]
22.01 POST OFFICE	.00081	.00121	.00160	.00062	.00182	.00029	.00145	.00074	.00058	.00052	.00234	.00253	.00322
23.01 SCRAP+SECOND-HAND GOODS	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.02 GOVERNMENT INDUSTRY	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.03 REST-OF-THE-WORLD INDUS	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.04 HOUSEHOLD INDUSTRY	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24.00 DOMESTIC INTERMT INPUT	.37740	.42144	.45884	.30633	.41605	.65182	.49695	.44314	.57408	.46113	.32449	.38958	.41234
25.00 DOMESTIC VALUE ADDED	.62260	.57856	.33888	.55029	.51851	.19324	.47272	.53248	.37437	.35827	.67551	.61042	.52479
26.00 TOTAL IMPORTS	0.00000	0.00000	.20227	.14338	.06545	.15494	.03032	.02438	.05155	.18061	0.00000	0.00000	.06287
27.00 SOCIAL SAVINGS/COST	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
28.00 TOTAL INPUT/OUTPUT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

TABLE 4. DIRECT TECHNICAL COEFFICIENTS, WORLD I

The Transactions Table. This table tells us a great deal about the real world economy. For example, if 1978 had been a year of peacetime full employment, the total outputs (U.S. domestic outputs plus imports) provided by the steel and motor vehicles sectors would have been $65.0 billion and $144.8 billion, respectively.* Also, in that year, the steel industry would have sold directly to the motor vehicles industry $12.4 billion worth of iron and carbon steel (shown at the intersection of column 11.01 and row 7A01, as noted in Table 6). This cell thus accounts for 19 percent of the supply of steel and 8.6 percent of the direct input requirements of motor vehicles.

Turning our attention now to some economic aggregates, the transactions table shows us that, in full employment 1978, the entire economy would have operated at a GNP (gross national product) level of some $2,243.0 billion.**

It should be emphasized that private fixed capital formation--i.e., private industrial investment in plant and equipment--is part of final demand GNP, but is calculated rather than given in this version of the I/O model. The noncapital portions of final demand and the dynamic inverse enter into the computations that provide each sector's total output. These total outputs, along with the B, G and R matrices allow the computation of each sector's new investment. It should also be noted that another column vector of final demand has been added to this model, the so-called "cargo losses" which occur as a result of fracture-related transportation accidents. These cargo losses, like any other final demand, remove resources from the production flow. We show them separately, here, rather than "bury" them in new investment, exports, and net inventory change.

Model Outputs: World II

To the extent that anything was changed in adjusting World I values to provide the World II realistic base for calculating the cost of fracture, these changes are included among the printouts of Appendix H. The significance of these changes and the ways they can be utilized in analyses of the costs of fracture are summarized below.

Data Bases

Many changes have been made from World I technologies in the A, B, and R matrices, and in noncapital final demands. All reflect the

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* These are the amounts (rounded from millions to billions) shown in the TO (total output) column on rows 7A01 (Iron and Carbon Steel) and 11.01 (Motor Vehicles and Parts) for World I. Table 5 also reports the 11.01 total.

** This is shown in two places: (a) it is the row-sum of value added, where that row intersects the TIO (total intermediate output) column; or (b) it is the column-sum of TFD (total final demand), where that column intersects the Total Input/Output row. See Appendix H.

TABLE 5. TOTAL OUTPUT

TOTAL OUTPUT (MILLION 1975 DOLLARS)

	I	II	III	I-II	I-III	III-II
1.01 LIVESTK+LIVESTK PRODUCTS	41435.63	40872.41	41235.04	623.22	260.59	362.63
1.02 FIELD + ORCHARD CROPS	63931.40	62986.77	63686.85	944.64	244.54	700.09
1A03 FORESTRY PRODUCTS	4170.30	4009.49	4455.77	160.80	-285.46	446.28
1603 FISHNG,HUNTNG,TRAPPING	2854.52	2847.92	2851.39	6.61	3.14	3.47
1.04 AGRI, FORST + FISH SERVC	2434.17	2380.23	2420.80	53.94	13.37	40.58
2.01 IRON + FERROALLOYS ORES	6450.11	3766.00	5350.87	2684.11	1099.23	1584.87
2X02 NONFERROUS ORES MINE	4413.71	3479.25	4061.79	934.46	351.93	582.53
2A04 UNDERGROUND COAL MINE	9324.58	7930.11	8538.84	1394.48	785.74	708.74
2B04 STRIP COAL MINING	14692.46	13302.12	14098.65	1390.34	593.81	796.52
2C04 OTHER COAL MINING	291.58	282.28	288.23	9.30	3.35	5.95
2A05 CRUDE PETROLEUM	83400.10	80270.05	82406.96	3130.05	993.14	2136.90
2B05 NATURAL GAS	13265.38	12559.97	13063.09	706.40	202.29	504.12
2.06 STONE + CLAY MINING	9644.63	8507.45	9612.52	1137.18	32.11	1105.07
2.07 CHEM + FERTLZR MINERALS	1884.78	1724.63	1821.59	160.15	63.18	96.97
3A01 BEVERAGES	37273.41	37078.58	37203.90	194.83	69.51	125.32
3B01 OTHER FOOD+KINDRED PRD	203477.37	202721.88	203152.11	755.49	325.26	430.23
3.02 TOBACCO MANUFACTURES	14643.84	14617.15	14636.98	26.69	4.86	21.83
3X03 LEATHR+LEATHR PRD	11498.83	11457.09	11480.15	41.74	18.68	23.06
3X05 FAB,YARN,THRD+SFLOOR COV	29527.92	29212.46	29404.33	315.46	123.59	191.87
3A07 METAL TIRE CORD	474.52	123.32	492.81	351.20	-18.29	369.49
3B07 OTHER CORD+MISC TEXT PR	3678.87	3370.70	3658.76	308.17	20.11	288.06
3X08 APPRL+MISC FAB TEXT PRD	55583.15	55457.60	55526.91	125.55	56.24	69.30
4.01 SAWMILLS + PLANING MILLS	10136.11	9002.71	9588.89	1133.40	547.23	586.17
4.02 VENEER,PLYWOOD+LAM WD	7694.09	7584.76	7649.49	109.32	44.60	64.72
4.03 OTHER LMBR+WD EX CONTNRS	20100.79	19401.40	19794.44	699.39	306.35	393.05
4.04 WOODEN CONTAINERS	887.89	840.18	876.97	47.71	10.92	36.79
4XA5 WOOD FURNITUR+FIXTUR	15559.34	15485.00	15531.49	74.34	27.85	46.48
4XB5 METAL FURNTR+FIXTURES	6340.78	6271.53	6316.33	69.26	24.45	44.80
4.07 PULP+PAPR PRD EX CONTNRS	68177.90	67021.41	67737.94	1156.49	439.97	716.52
4.08 PAPERBRD CONTAINERS+BOX	13118.33	12681.67	13027.36	436.66	90.98	345.69
5.01 PETROL REFNG + RELTD PRD	128263.18	124056.04	127050.84	4207.14	1212.34	2994.80
5.02 PAVING MIX+ASPHALT PRD	2887.51	2790.03	2865.19	97.48	22.32	75.16
5.03 INDUSTRL INORG+ORG CHEM	44874.04	42178.22	43959.05	2695.81	914.98	1780.83
5X04 AGRICULTURAL CHEMICALS	5351.16	5292.01	5333.62	59.15	17.53	41.61
5A06 ADHESIVES	2609.30	2499.72	2579.95	109.57	29.35	80.22
5B06 OTHER CHEMICAL PRD	4726.80	4596.41	4684.52	130.39	42.27	88.11
5.03 DRUGS	12839.95	12819.47	12830.85	20.48	9.10	11.38
5X10 CLEANING+TOILET PREP	16602.61	16524.02	16572.00	78.59	30.62	47.97
5.12 PAINTS+ALLIED PRD	5363.29	5223.64	5310.12	139.66	53.17	86.49
P.07 PLAST MATR,RESIN+SYN RUB	16721.94	14575.26	15501.05	2146.69	1220.39	925.80
P.08 ORGANIC MANMADE FIBERS	5822.25	5548.94	5958.43	273.31	-136.18	409.48
P.13 TIRES+INNER TUBES	10722.42	10528.09	10658.49	194.33	63.93	130.40
PA14 INDUSTRIAL RUBBER BELTS	3046.51	2881.15	2992.82	165.36	53.69	111.68
PB14 OTHER RUBBER PRO	4957.56	4877.43	4925.02	80.13	32.53	47.60
PA15 PLASTIC PIPE	3533.77	3472.40	3512.76	61.37	21.00	40.36
PB15 PLASTIC CONTAINERS	3692.45	3635.38	3669.29	57.07	23.16	33.91
PC15 OTHER MANF PLASTIC PRD	13376.97	13094.11	13288.60	282.86	88.36	194.49
6A01 FLAT GLASS	1605.69	1557.69	1585.14	48.00	20.55	27.46
6B01 GLASS CONTAINERS	5159.98	5067.01	5123.99	92.97	36.00	56.98
6C01 AUTO+TRUCK WINDSHIELDS	712.05	691.62	702.75	20.43	9.30	11.13
6D01 OTHER GLASS PRD	3163.60	3096.23	3134.65	67.37	28.93	38.44
6.02 CEMENT+LIME+GYPSUM PRD	4709.49	4345.70	4620.10	363.78	89.39	274.40
6A03 STR CLAY PRD EX REFRAC	5994.14	5868.26	5953.63	125.88	40.50	85.37
6B03 STR CONCRET PRO+CEMENT	15075.48	14421.98	15736.39	653.49	-660.91	1314.40
6C03 POTRY+WHTWR+PORCLN PRD	2296.23	2242.34	2273.93	53.89	22.30	31.59

TABLE 5. (Continued)

TOTAL OUTPUT (MILLION 1976 DOLLARS)

	I	II	III	I-II	I-III	III-II
6D03 CLAY+NCLAY REFRACTORIES	4249.49	2614.94	3709.08	1634.46	540.32	1094.14
6A04 ABRASIVES INC GRIND WH	4103.32	3313.58	4030.90	189.74	72.42	117.33
6B04 OTHER NONMET MINERAL PRD	4000.30	3833.03	3935.86	167.27	64.44	102.83
7A01 IRON,CARBN STEEL+COKE	64969.56	37368.75	54209.09	27600.81	10760.47	16840.34
7B01 ALLOY STEEL	3226.81	1834.53	2759.09	1392.28	457.72	934.55
7C01 STAINLESS STEEL	2706.70	1584.55	2274.61	1122.15	432.09	690.06
7.03 PRIMARY ALUMINUM	14182.87	7924.84	11809.52	6258.03	2373.35	3884.68
7X04 OTHER NONFERROUS METALS	22468.72	15257.26	19875.45	7211.45	2593.26	4618.18
8.01 METAL CANS	5681.51	5556.71	5636.88	124.80	44.63	80.17
8.02 METAL BARRELS,DRUM+PAILS	1150.98	1094.00	1128.87	56.99	22.11	34.88
8.03 MET SANIT+PLUMBING PRD	1550.35	1521.35	1541.01	29.00	9.34	19.66
8.04 NONELEC HEATING EQUIP	3950.37	3882.40	3927.17	57.97	23.21	44.77
8A05 STRUCTURAL METAL	10859.17	10618.30	10784.13	240.87	75.04	165.83
8B05 BOILER SHOP PRD	4135.58	3969.52	4077.83	166.06	57.75	108.31
8C05 OTHER FAB STRUCTRL PRD	18042.07	17498.50	17897.17	543.57	144.90	398.67
8.06 SCRW MACH PRD+STAMPNGS	14484.72	13499.00	14311.72	985.72	172.99	812.72
8.07 FABRICATED METAL PRD	25168.02	24469.43	24909.36	698.59	258.66	439.93
9.01 ENGINES + TURBINES	12148.42	11792.64	12001.95	355.78	146.48	209.30
9.02 GEN INDUS MACH+EQUIP	19311.73	18383.32	18964.64	928.41	347.09	581.32
9.03 MACHINE SHOP PRD	6253.92	5937.91	6113.07	316.01	140.85	175.16
10.01 FARM MACHINERY	5732.54	5608.77	5690.50	123.77	42.04	81.73
10.02 CONSTRUCTION MACHINERY	13930.18	13211.11	13677.33	719.07	252.85	466.22
10.03 MINING MACHINERY	1942.34	1645.68	1829.38	236.66	112.96	183.70
10.04 OIL FIELD MACHINERY	1223.19	1145.04	1195.91	78.14	27.27	50.87
10.05 MTRL-HNDLNG MACH EX TRUC	7891.56	7161.45	7580.37	730.11	311.19	418.92
10.06 INDUST TRUCKS + TRACTORS	3036.87	2940.68	3000.83	96.19	36.04	60.15
10.07 METAL WORKING MACHINERY	16200.98	14776.69	15845.40	1424.29	355.58	1068.71
10.08 SPECL INDSTRY MACHINERY	15157.49	14366.35	14847.15	791.14	310.34	480.80
11.01 MOTOR VEHICLES + PARTS	144803.51	141553.77	143366.91	3249.75	1436.61	1813.14
11.02 AIRCRAFT + PARTS	34249.51	33211.72	33866.14	1037.79	383.37	654.42
11.03 SHIP+BOAT BLDG + REPAIRS	8523.92	8256.65	8407.23	267.27	116.68	150.59
11.04 LOCOMS+RAIL+RPD TRNST	3755.33	3412.75	3637.03	342.58	118.30	224.28
11.05 CYCLES,TRAILERS, ETC	9193.28	9063.78	9133.17	129.50	60.11	69.39
12.01 ELEC MEASURING INSTRUMTS	5208.22	5027.86	5144.52	180.36	63.70	116.66
12A02 ELEC MOTRS+GENRTRS,POWPL	359.10	355.01	357.45	4.09	1.64	2.45
12B02 OTHER ELEC MOTRS+GENRTRS	6035.01	5907.86	5941.61	227.15	93.40	133.75
12.03 INDUS CONTRL,TRANSFM,ET	12199.45	11693.07	12008.31	506.38	191.14	315.24
12.04 ELECTRIC LAMPS	3024.79	2995.52	3012.53	29.27	12.19	17.08
12.05 LIGHT FIXT+WIRING DEVICE	8818.23	8567.60	8719.80	250.62	98.43	152.20
12.06 ELECTRNC COMPNTS+ACCESS	10576.97	10405.69	10505.75	171.29	71.22	100.07
12A07 X-RAY EQUIPMENT	843.01	836.30	841.23	6.72	1.78	4.93
12B07 OTHER MISC ELEC MACH	8087.14	7925.11	8017.20	162.04	69.35	92.09
13.01 SERVC INDUSTRY MACHINERY	12580.90	12304.05	12473.99	276.85	106.91	169.94
13.02 HOUSEHOLD APPLIANCES	11122.48	11073.20	11099.81	49.28	22.67	26.61
13.03 RADIO,TV+COMMUN EQUIP	31803.71	31597.28	31720.30	206.43	83.41	123.02
14A01 FRACTURE CONTROL INSTR	593.22	567.21	584.14	26.01	9.08	16.92
14B01 OTHER SCNC INSTR,ETC	10461.20	10225.93	10369.09	235.27	92.12	143.15
14.02 MED,SURGCL,DENTAL INSTR	2982.40	2944.27	2968.53	38.13	13.83	24.30
14.03 WATCHES,CLOCKS + PARTS	2259.74	2245.82	2253.79	12.93	5.96	6.97
14.04 OPTICAL+OPTHALMIC GOODS	2688.79	2654.77	2677.52	34.02	11.28	22.75
14.05 PHOTO EQUIP + SUPPLIES	6230.73	6165.67	6202.41	65.06	29.32	36.74
15.01 COMPUTING+RELAT MACHINES	18228.31	17924.46	18105.40	303.84	122.92	180.92
15.02 OTHR OFFICE+BUSIN MACH	4998.18	4802.11	4913.53	196.07	84.65	111.41
15.03 OFFICE SUPPLIES	9504.18	9320.84	9449.83	183.34	54.35	128.99
16.01 ORDNANCE + ACCESSORIES	12673.22	12652.19	12665.01	21.03	8.21	12.82

TABLE 5. (Continued)

TOTAL OUTPUT (MILLION 1978 DOLLARS)

	I	II	III	I-II	I-III	III-II
16A02 SPORTING GOOD+TOYS	9839.47	9826.66	9834.81	12.81	4.66	8.15
16B02 OTHER MISC PRD	16428.96	16256.27	16364.77	172.69	64.19	108.49
17.01 RAILROADS+RELATD SERVCS	27653.57	24889.60	26794.30	2763.97	859.27	1904.70
17.02 LOCAL+HIGHWAY PASSNGR TR	14320.72	14164.56	14266.06	156.16	54.66	101.50
17.03 MOTOR FREIGHT+WAREHOUSE	39882.33	36336.42	38898.02	3545.91	984.31	2561.59
17.04 WATER TRANSPORTATION	14558.83	13688.76	14250.40	870.07	308.43	561.64
17.05 AIR TRANSPORT	19536.37	19375.86	19486.69	160.51	49.68	110.83
17.06 PIPE LINES	2454.48	2370.21	2427.95	84.27	26.53	57.74
17.07 TRANSPORTATION SERVICES	2013.81	1988.89	2005.44	24.93	8.37	16.56
18.01 TELECOMMUNICATION	47479.57	47104.49	47348.40	375.08	131.17	243.91
18.02 ELECTRIC POWER	61875.65	60253.69	61323.61	1621.97	552.04	1069.92
18.03 GAS	68756.59	64957.00	67670.56	3799.59	1086.03	2713.56
18.04 WATER + SANITARY SERVICE	13882.30	13648.12	13800.45	234.18	81.84	152.33
19.01 NEW CONST,NONFARM RESID	129867.65	129760.60	129920.95	107.05	-53.31	160.35
19.02 CONST,NONRESID BUILD	115124.11	111621.57	114015.23	3502.53	1108.88	2393.65
19A03 CONST,RAILROADS	4080.05	3658.46	3958.74	421.59	121.31	300.28
19B03 CONST, PIPELINES	468.08	450.93	463.37	17.16	4.71	12.45
19C03 OTHER PU, CONST	37488.70	36849.28	37296.41	639.41	192.29	447.12
19A04 CONST,HIGHWAYS	17850.43	17177.18	17901.48	673.24	-51.06	724.30
19B04 CONST,BRIDGES	5805.57	5779.35	5815.40	26.22	-9.83	36.05
19C04 CONST, DAMS	3283.70	3279.29	3284.34	4.41	-.64	5.05
19D04 CONST, ALL OTHER	13407.67	13195.35	13347.06	212.31	60.61	151.71
20.01 WHOLESALE+RETAIL TRADE	398146.79	395171.53	396963.03	2975.26	1183.76	1791.50
20XA2 INSURANCE	56130.66	55716.93	55996.97	413.74	133.69	280.04
20XB2 FINANC,REAL EST+ADVERTSG	394999.26	392248.72	394021.91	2750.55	977.36	1773.19
20A05 FRACT RESEAR+DEVEL	1017.46	0.00	1006.02	1017.46	11.45	1006.02
20B05 OTHER RESEARCH + DEVEL	46679.10	45195.52	46138.03	1483.58	541.07	942.51
20C05 ENVIRONMENTAL CLEANUP	1117.03	984.93	1059.18	132.10	57.85	74.25
20D05 OTHR BUSNS+PROFESNL SERV	81336.00	79830.41	80662.91	1505.59	673.09	832.49
20.06 BUS TRAVEL,ENTER+GIFTS	27666.09	26998.51	27432.45	657.58	233.63	433.95
21.01 PRINTING + PUBLISHING	34103.16	33831.24	34008.69	271.92	94.48	177.44
21.02 RADIO + TV BROADCASTING	20.20	20.01	20.13	.19	.07	.12
21.03 HOTELS + LODGING PLACES	13250.89	13175.48	13223.20	75.40	27.69	47.72
21A04 PERSONAL SERVICES	16640.38	16632.80	16637.67	7.58	2.70	4.87
21B04 REPAIR SERV, EXC AUTO	10841.92	9730.18	10288.97	1111.74	552.95	558.79
21.05 AUTOMOBILE REPAIR+SERVC	46343.19	45600.28	46445.19	742.90	297.39	444.91
21.06 AMUSEMENTS	24504.76	24485.10	24497.98	19.65	6.77	12.88
21.07 MEDICAL + HEALTH SERVICE	69972.91	69948.31	69963.80	24.60	9.11	15.49
21.08 EDUCAT SERVC+NONPROF ORG	112625.25	112509.63	112586.23	115.63	39.02	76.61
22.01 POST OFFICE	17194.07	17011.58	17126.80	182.49	67.27	115.22
23.01 SCRAP+SECOND-HAND GOODS	13160.88	13160.88	13160.88	0.00	0.00	0.00
23.02 GOVERNMENT INDUSTRY	239062.90	238887.90	239238.80	175.00	-175.90	350.90
23.03 REST-OF-THE-WORLD INDUS	33366.05	33366.05	33366.05	0.00	0.00	0.00
23.04 HOUSEHOLD INDUSTRY	7897.74	7897.74	7897.74	0.00	0.00	0.00

FRACTURE WORLD I   PAGE 29

DOLLAR VALUES OF INTERINDUSTRY AND FINAL TRANSACTIONS (IN MILLIONS OF DOLLARS), UNITED STATES, 1978

	10.07	10.08	11.01	11.02	11.03	11.C4	11.05	12.01	12A02
6D03 CLAY+NCLAY REFRACTORIE	0.0	.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6A04 ABRASIVES INC GRIND WH	73.4	23.9	250.7	96.4	34.4	0.0	120.3	0.0	2.4
6B04 OTHER NONMET MINERAL P	31.5	10.3	167.1	96.4	34.4	0.0	51.6	0.0	1.5
7A01 IRON,CARBN STEEL+COKE	907.6	1020.2	12398.5	29.4	261.0	627.5	270.5	1.4	22.9
7B01 ALLOY STEEL	38.2	60.0	522.0	249.8	11.0	26.4	11.4	2.7	3.0
7C01 STAINLESS STEEL	9.6	120.0	130.5	14.7	2.7	6.6	2.8	23.3	0.0
7.03 PRIMARY ALUMINUM	54.3	85.0	1503.5	144.1	40.9	28.0	257.4	27.9	4.1
7X04 OTHER NONFEROUS METALS	171.9	189.0	594.5	908.0	139.7	.9	25.7	29.1	16.1
8.01 METAL CANS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.02 METAL BARRELS,DRUM+PAI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.03 MET SANIT+PLUMBING PRD	0.0	0.0	0.0	0.0	2.0	.8	64.1	0.0	0.0
8.04 NONELEC HEATING EQUIP	0.0	29.3	0.0	0.0	58.0	0.0	131.3	0.0	0.0
[illegible] METAL	1.9	57.8	0.0	0.0	170.3	.0	7.1	0.0	0.0
[illegible] D	6.3	173.3	0.0	0.0	56.8	.1	14.3	0.0	0.0
[illegible] L PRD	4.4	154.0	0.0	0.0	56.8	.2	121.2	0.0	0.0
[illegible]	[illegible]	64.2	5289.8	635.2	12.2	17.9	61.6	118.4	3.6
[illegible]	[illegible]	248.1	2395.8	249.9	289.8	17.4	140.6	14.5	1.2
[illegible]	[illegible]	[illegible]	[illegible]	6.8	398.7	74.1	0.0	0.0	.3
[illegible]	[illegible]	[illegible]	[illegible]	273.5	150.9	27.7	42.9	6.0	7.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	62.9	5.2	0.0	.3	.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0	0.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83.4	0.0	0.0	0.0	0.0
19.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0
19.02 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0
19A03 CONST,RAILRO[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	.0
19B03 CONST, PIPELINE[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	.0
19C03 OTHER PU, CONST	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.1
19A04 CONST,HIGHWAYS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0
19B04 CONST,BRIDGES	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19C04 CONST, DAMS	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19D04 CONST, ALL OTHER	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20.01 WHOLESALE+RETAIL TRADE	328.9	289.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20XA2 INSURANCE	17.1	12.0	83.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20XB2 FINANC,REAL EST+ADVERT	289.9	246.3	1076.2	223.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20A05 FRACT RESEAR+DEVEL	4.3	5.6	61.5	87.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20B05 OTHER RESEARCH + DEVEL	207.1	272.8	3014.4	1001.0	97.1	[illegible]	[illegible]	[illegible]	[illegible]
20C05 ENVIRONMENTAL CLEANUP	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]
20D05 OTHR BUSNS+PROFESNL SE	76.0	126.9	210.6	136.5	63.7	[illegible]	[illegible]	[illegible]	[illegible]
20.06 BUS TRAVEL,ENTER+GIFTS	149.9	106.8	101.8	215.2	31.3	[illegible]	[illegible]	[illegible]	[illegible]
21.01 PRINTING + PUBLISHING	.8	2.2	0.0	32.6	5.8	.9	.4	[illegible]	[illegible]
21.02 RADIO + TV BROADCASTIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
21.03 HOTELS + LODGING PLACE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
21A04 PERSONAL SERVICES	8.4	3.6	5.4	0.0	0.0	0.0	0.0	2.6	[illegible]
21B04 REPAIR SERV, EXC AUTO	8.4	3.6	5.4	0.0	24.9	0.0	1.7	2.6	[illegible]
21.05 AUTOMOBILE REPAIR+SERV	7.6	4.7	2786.0	3.5	9.0	2.8	1.7	4.0	.2
21.06 AMUSEMENTS	.4	0.0	0.0	0.0	.1	.1	.2	.1	0.0
21.07 MEDICAL + HEALTH SERVI	0.0	0.0	0.0	6.4	.5	.4	2.3	.7	.1
21.08 EDUCAT SERVC+NONPROF O	16.2	22.6	49.8	44.0	9.9	2.5	5.3	9.9	.5
22.01 POST OFFICE	13.1	27.7	41.5	49.6	6.3	2.2	4.8	12.2	.9
23.01 SCRAP+SECOND-HAND GOOD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.02 GOVERNMENT INDUSTRY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.03 REST-OF-THE-WORLD INDU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.04 HOUSEHOLD INDUSTRY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.00 DOMESTIC INTERMT INPUT	4962.9	6306.2	94386.0	17020.5	3777.3	2155.9	4239.3	1690.0	139.9
25.00 DOMESTIC VALUE ADDED	8915.2	7859.3	27981.3	16190.5	4538.8	1405.9	3293.6	3518.2	219.2
26.00 TOTAL IMPORTS	2322.9	992.0	22436.2	1038.6	207.8	193.6	1660.4	0.0	0.0
27.00 SOCIAL SAVINGS/COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.00 TOTAL INPUT/OUTPUT	16201.0	15157.5	144803.5	34249.5	8523.9	3755.3	9193.3	5208.2	359.1

TABLE 6. DOLLAR VALUES OF INTERINDUSTRY AND FINAL TRANSACTIONS, WORLD I

technological and demand changes expected to flow from the fact that, in World II:

- Characteristics of materials are uniformly at the high end of attainable distributions;

- Functional requirements for all artifacts are precisely known, along with the material characteristics and design rules;

- Time dependent fracture processes do not occur; and

- Nothing breaks within designed loads.

For example, it has been calculated that, in World II, any metal input for purely load bearing purposes (i.e., no stiffness requirement constraints, aesthetic considerations, etc.) could be reduced to 51 percent of its World I level. In World I, the direct technical coefficient for iron/carbon steel going into motor vehicles (i.e., the A matrix cell defined by row 7A01 and column 11.01) was 0.08562, indicating that iron/steel contributed almost 9 cents of every average $1.00 value of a motor vehicle. In going to World II, this coefficient was reduced to 0.04323, which is 50.4 percent of the World I value. In addition to the metal reduction, there was also a small scrappage rate adjustment made in column 11.01 that accounts for the rest of the reduction. We treat this reduction in steel inputs as a positive saving in the use of resources.

Viewed in a slightly different way, we subtract 0.04239--that is (.08562-.04323)--from cell 7A01/11.01 (steel into vehicles) and add it into the cell ("Social Savings/Cost") in the same column.* As each affected coefficient in the World I column for, say, 11.01 is adjusted to its World II value, reductions in inputs will be offset by <u>adding</u> them to social savings; conversely, increases in inputs will be offset by <u>subtracting</u> them from the social savings row. In the end, after all adjustments are made, there will be a net social saving (shown with no sign or a plus) or a net social cost (shown with a <u>minus</u> sign). In the case of motor vehicles (11.01), the net value is +0.06507, or a social saving of nearly 7 cents per dollar of motor vehicle output (see Table 7). There are no sectors which show net social costs in the World II A matrix.

As indicated in Chapter V and Appendix D, similar types of changes have been made in the capital coefficients (B matrix) and annual capital replacement rates (R matrix). These changes are not, however, as many or as significant in these matrices, nor have the changes been balanced by use of the social savings/cost row.

Noncapital final demands--made up of consumer expenditures (PCE), exports (EXP), defense and civilian Federal expenditures (FGED and FGEC),

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* It should be noted that, by definition, the "Social Savings Cost" row is empty in World I.

DIRECT TECHNICAL COEFFICIENTS, UNITED STATES 1978

FRACTURE WORLD II PAGE 20

	10.04	10.05	10.06	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02	12802
6003 CLAY+NCLAY REFRACTORIES	0.00000	0.00000	0.00000	0.00000	.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6A04 ABRASIVES INC GRIND WH	.00010	0.00000	0.00000	.00449	.00156	.00171	.00281	.00403	0.00000	.01295	0.00000	.00676	.00823
6804 OTHER NONMET MINERAL PRO	.00007	0.00000	0.00000	.00192	.00067	.00114	.00281	.00403	0.00000	.00555	0.00000	.00422	.00183
7A01 IRON,CARBN STEEL+COKE	.04801	.04298	.06686	.04160	.04198	.04323	.00269	.01556	.08437	.01486	.00013	.03253	.03499
7801 ALLOY STEEL	.00202	.00181	.00282	.00175	.00247	.00182	.00190	.00066	.00355	.00063	.00027	.00431	.00700
7C01 STAINLESS STEEL	.00051	.00045	.00070	.00044	.00494	.00046	.00014	.00016	.00089	.00016	.00228	0.00000	0.00000
7.03 PRIMARY ALUMINUM	.00054	.00182	.00254	.00295	.00350	.00524	.00147	.00244	.00377	.01413	.00273	.00582	.00560
7X04 OTHER NONFEROUS METALS	.00133	.00203	.00345	.00788	.00778	.00242	.00371	.00834	.00012	.00141	.00558	.04477	.04665
8.01 METAL CANS	.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8.02 METAL BARRELS,DRUM+PAILS	.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8.03 MET SANIT+PLUMBING PRO	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.00024	.00021	.00590	0.00000	0.00000	0.00000
ELEC HEATING EQUIP	0.00000	0.00000	0.00000	0.00000	.00191	0.00000	0.00000	.00679	0.00000	.01414	0.00000	0.00000	0.00000
URAL METAL	0.00000	.00040	0.00000	.00012	.00377	0.00000	0.00000	.01993	.00001	.00077	0.00000	0.00000	0.00000
HOP PRO	0.00000	.00063	0.00000	.00038	.01132	0.00000	0.00000	.00664	.00003	.00154	0.00000	0.00000	0.00000
PRO	0.00000	.00055	0.00000	.00027	.01006	0.00000	0.00000	.00664	.00004	.01305	0.00000	0.00000	0.00000
GS	.00859	.00531	.02739	.00632	.00419	.03617	.00185	.00143	.00471	.00664	.02273	.01014	.01281
	1802	.00909	.00079	.00293	.01620	.01638	.00730	.03392	.00459	.01515	.00279	.00338	.00457
		.00053	.04018	0.00000	.00007	.00263	.00020	.04619	.01934	0.00000	0.00000	.00084	.00045
		.03476	02977	.02102	.03642	.00848	.00790	.01748	.00723	.00458	.00114	.02091	.02717
			151	.00111	.00253	.01495	.00956	.00728	.00135	0.00000	.00006	.00017	.00009
				0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
					0.00000	0.00000	0.00000	.00878	0.00000	0.00000	0.00000	0.00000	0.00000
1					00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19.					000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19A03							0.00000	.00346	.00164	.00048	0.00000	.00004	.00012
19803 CONST, P							00000	.00143	.00037	.00056	0.00000	.00008	.00016
19C03 OTHER PU, C							809	.00171	.00769	0.00000	.00231	.01673	.01811
19A04 CONST,HIGHWAY									0.00000	0.00000	0.00000	0.00000	.00004
19804 CONST,BRIDGES									00003	.01857	0.00000	0.00000	0.00000
19C04 CONST, DAMS	0.									0.00000	0.00000	0.00000	0.00000
19004 CONST, ALL OTHER	0.00									00	0.00000	0.00000	0.00000
20.01 WHOLESALE+RETAIL TRADE	.01347	.00580									0.00000	0.00000	0.00000
20XA2 INSURANCE	.00023	.00108										00000	0.00000
20X82 FINANC,REAL EST+ADVERTSG	.00956	.01203	.02									017	.00018
20A05 FRACT RESEAR+DEVEL	0.00000	0.00000	0.00000	0.0000								8	0.00000
20805 OTHER RESEARCH + DEVEL	.01016	.03785	.03090	.01266									
20C05 ENVIRONMENTAL CLEANUP	0.00000	0.00000	0.00000	0.00000	0.00000	0.							
20005 OTHR BUSNS+PROFESNL SERV	.00646	.00430	.00376	.00464	.00829	.00							
20.06 BUS TRAVEL,ENTER+GIFTS	.00789	.00386	.00728	.00916	.00697	.0007							
21.01 PRINTING + PUBLISHING	.00008	0.00000	.00012	.00005	.00015	0.00000	.00095						
21.02 RADIO + TV BROADCASTING	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0					
21.03 HOTELS + LODGING PLACES	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.0					
21A04 PERSONAL SERVICES	0.00000	0.00000	0.00000	.00051	.00023	.00004	0.00000	0.00000	0.00000				
21804 REPAIR SERV, EXC AUTO	.00059	.00013	.00023	.00046	.00021	.00003	0.00000	.00263	0.00000				
21.05 AUTOMOBILE REPAIR+SERVC	.00070	.00128	.00144	.00046	.00031	.01893	.00010	.00104	.00073	.00			
21.06 AMUSEMENTS	.00004	0.00000	0.00000	.00002	0.00000	0.00000	0.00000	.00002	.00001	.00002	.000		
21.07 MEDICAL + HEALTH SERVICE	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.00019	.00006	.00010	.00025	.00014		
21.08 EDUCAT SERVC+NONPROF ORG	.00133	.00130	.00135	.00099	.00148	.00034	.00128	.00116	.00065	.00057	.00190	.00127	
22.01 POST OFFICE	.00080	.00120	.00158	.00061	.00181	.00028	.00145	.00074	.00058	.00052	.00234	.00253	.
23.01 SCRAP+SECOND-HAND GOODS	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.02 GOVERNMENT INDUSTRY	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.03 REST-OF-THE-WORLD INDUS	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.04 HOUSEHOLD INDUSTRY	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24.00 DOMESTIC INTERMT INPUT	.32119	.36691	.40391	.28278	.37338	.59154	.43130	.40637	.47499	.42003	.31855	.34510	.36208
25.00 DOMESTIC VALUE ADDED	.61254	.56921	.33341	.54139	.51013	.18844	.38962	.51713	.36802	.35219	.67551	.60663	.51893
26.00 TOTAL IMPORTS	0.00000	0.00000	.20227	.14338	.06545	.15494	.03032	.02438	.05155	.18061	0.00000	0.00000	.06287
27.00 SOCIAL SAVINGS/COST	.06628	.06389	.06041	.03244	.05104	.06507	.14876	.05213	.10544	.04717	.00594	.04827	.05612
28.00 TOTAL INPUT/OUTPUT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

TABLE 7. DIRECT TECHNICAL COEFFICIENTS, WORLD II

state and local goverment expenditures (S/L), net inventory change (NIC), and cargo losses (LOSS)--are also subject to changes from World I to World II. In total, these amount to some $6 billion (as shown on the Social Saving row as the difference between TFD and PFCF, that is, between total final demand and private fixed capital formation). Noncapital motor vehicles demand also changed, from a World I value of $71.3 billion ($95.0-$23.7 billion) to a World II of $71.0 billion ($94.0-$23.0 billion), a decline of only about $300 million.

Calculated Outputs

The changes in the data bases lead to corresponding changes in the calculated outputs for World II. It should be noted, however, that the dynamic inverse integrates <u>all</u> the changes made in the A, B, and R matrices, and the final computation of the transaction table integrates these with the final demand alterations. Thus the World I-World II changes may be surprising when compared with any of the individual adjustments that gave rise to them.

<u>The Inverse</u>. It will be recalled that the 7A01/11.01 inverse for World I was approximately 19 cents (0.18840) per dollar of motor vehicle output. After all the matrix changes have been made to give effect to World II technologies, the new inverse is 0.0990 (see Table 8). In other words, not only did the amount of iron and steel per vehicle dollar decline by about 7 cent's worth, there were also many indirectly felt reductions that accounted for an additional 3 cents per dollar.

<u>The Transactions Table</u>. When the full computations of the World II economy is completed, the resulting transactions table will differ from that for World I in three distinct ways:

- Differences in technologies introduced into the data bases
- Differences in total final demands (noncapital, as introduced into the data base; and capital, as calculated)
- Differences in indirectly derived interindustry demands.

As already noted, the technological differences are indicated by the entries in the social savings/cost row of the A matrix. The final demand differences are similarly displayed in the same row across the final demand portion of the World II transaction table. The dollar values entered in the Social Savings/ Cost row across the intermediate portion of the same World II transactions table reflect the net impacts of all three of these influences (these are listed for all Worlds in Table 9). As we will show in the analyses of Chapter VIII, below, these influences are somewhat difficult to isolate and measure separately.

WORLD II PAGE 20

DIRECT AND INDIRECT EFFECTS, UNITED STATES, DYNAMIC,1978

	10.04	10.05	10.06	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02	12802
6D03 CLAY+NCLAY REFRACTORIES	.00279	.00268	.00370	.00247	.00287	.00362	.00077	.00179	.00503	.00149	.00083	.00243	.00272
6A04 ABRASIVES INC GRIND WH	.00095	.00128	.00157	.00601	.00310	.00435	.00461	.00609	.00150	.01614	.00099	.00838	.01006
6804 OTHER NONMET MINERAL PRO	.00074	.00085	.00104	.00313	.00177	.00302	.00432	.00546	.00107	.00800	.00066	.00556	.00330
7A01 IRON,CARBN STEEL+COKE	.07997	.07332	.10433	.06536	.07544	.09900	.01272	.04457	.14535	.03633	.01123	.05362	.05871
7801 ALLOY STEEL	.00296	.00291	.00411	.00249	.00381	.00374	.00309	.00196	.00563	.00125	.00083	.00529	.00836
7C01 STAINLESS STEEL	.00088	.00090	.00120	.00109	.00668	.00143	.00062	.00094	.00155	.00078	.00294	.00029	.00031
7.03 PRIMARY ALUMINUM	.00331	.00585	.00755	.00711	.01039	.01599	.00501	.00900	.01069	.02676	.00699	.01164	.01159
7X04 OTHER NONFEROUS METALS	.00558	.00865	.01060	.01449	.01531	.01182	.00959	.01568	.00898	.00786	.01385	.05529	.05775
8.01 METAL CANS	.00019	.00021	.00019	.00026	.00019	.00026	.00018	.00026	.00032	.00038	.00024	.00038	.00041
8.02 METAL BARRELS,DRUM+PAILS	.00017	.00023	.00020	.00014	.00022	.00032	.00016	.00057	.00033	.00033	.00027	.00032	.00038
8.03 MET SANIT+PLUMBING PRO	.00014	.00019	.00018	.00021	.00021	.00020	.00013	.00042	.00044	.00760	.00025	.00017	.00017
8.04 NONELEC HEATING EQUIP	.00033	.00050	.00045	.00048	.00260	.00049	.00032	.00740	.00040	.01561	.00056	.00041	.00042
8A05 STRUCTURAL METAL	.00121	.00210	.00163	.00181	.00594	.00170	.00114	.02190	.00157	.00236	.00194	.00153	.00155
8805 BOILER SHOP PRD	.00082	.00167	.00097	.00135	.01330	.00110	.00068	.00807	.00102	.00275	.00110	.00095	.00100
8C05 OTHER FAB STRUCTRL PRO	.00234	.00371	.00296	.00349	.01422	.00340	.00198	.00977	.00311	.01662	.00370	.00276	.00283
…ACH PRO+STAMPNGS	.01093	.00765	.03033	.00869	.00634	.05499	.00554	.00479	.00830	.01090	.02840	.01217	.01492
…ED METAL PRO	.02322	.01350	.00488	.00632	.02183	.02973	.01415	.04085	.00907	.02418	.00869	.00730	.00878
…URBINES	.00427	.00151	.04492	.00089	.00108	.00536	.00084	.05225	.02682	.00110	.00078	.00207	.00167
	…1213	.04500	.03690	.02744	.04610	.01884	.01355	.02467	.01488	.01020	.00559	.02657	.03369
	[illegible]	.00043	.02541	.00167	.00348	.02388	.01435	.01052	.00325	.00129	.00047	.00081	.00071
		.00014	.00011	.00009	.00010	.00013	.00009	.00011	.00009	.00024	.00011	.00018	.00020
		…128	.00149	.00126	.00133	.00158	.00072	.01028	.00174	.00118	.00107	.00146	.00151
				…062	.00070	.00088	.00024	.00056	.00113	.00048	.00031	.00077	.00082
					.00019	.00013	.00011	.00017	.00020	.00016	.00013	.00014	.00014
					…0371	.00549	.00321	.00709	.00587	.00501	.00380	.00349	.00369
					[illegible]	.00053	.00033	.00202	.00106	.00115	.00048	.00049	.00060
							[illegible]	.01428	.02210	.01173	.01598	.02707	.02893
								.00305	.00267	.00317	.00307	.00231	.00259
19.…								[illegible]	[illegible]	…3406	.00577	.00631	.00654
19A03 CO…											.00071	.00108	.00115
19803 CONST, PIPELINES											.00018	.00029	.00031
19C03 OTHER PU, CONST											…33	.00081	.00073
19A04 CONST,HIGHWAYS													…16
19804 CONST,BRIDGES	.00001	.00001											
19C04 CONST, DAMS	.00001	.00001	[illegible]										
19004 CONST, ALL OTHER	.00057	.00045	.0005…										
20.01 WHOLESALE+RETAIL TRADE	.02229	.01605	.04291	.02995	.030…								
20XA2 INSURANCE	.00165	.00334	.00382	.00292	.00288								
20X82 FINANC,REAL EST+ADVERTSG	.02235	.02564	.04330	.03177	.03277	.029…	[illegible]						
20A05 FRACT RESEAR+DEVEL	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.0000…					
20805 OTHER RESEARCH + DEVEL	.01663	.05042	.04123	.01987	.02703	.04018	.04549	.02253					
20C05 ENVIRONMENTAL CLEANUP	.00016	.00013	.00018	.00014	.00020	.00017	.00013	.00021	.0002…	[illegible]			
20005 OTHR BUSNS+PROFESNL SERV	.01153	.01045	.01120	.01015	.01481	.00911	.00994	.01483	.00861	.01158	.010…		
20.06 BUS TRAVEL,ENTER+GIFTS	.01251	.01061	.01376	.01413	.01295	.00767	.01363	.01032	.01283	.02499	.01903		
21.01 PRINTING + PUBLISHING	.00191	.00303	.00323	.00192	.00248	.00250	.00454	.00320	.00205	.00230	.01229	[illegible]	…0298
21.02 RADIO + TV BROADCASTING	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00005
21.03 HOTELS + LODGING PLACES	.00127	.00119	.00143	.00146	.00135	.00081	.00140	.00119	.00147	.00257	.00200	.00835	.00906
21A04 PERSONAL SERVICES	.00007	.00008	.00011	.00064	.00034	.00013	.00009	.00010	.00011	.00012	.00061	.00025	.00027
21804 REPAIR SERV, EXC AUTO	.00085	.00034	.00050	.00069	.00047	.00033	.00021	.00303	.00029	.00055	.00075	.00125	.00127
21.05 AUTOMOBILE REPAIR+SERVC	.00208	.00292	.00369	.00200	.00200	.02890	.00176	.00316	.00280	.00320	.00294	.00280	.00293
21.06 AMUSEMENTS	.00036	.00027	.00035	.00038	.00032	.00021	.00034	.00030	.00035	.00063	.00050	.00091	.00099
21.07 MEDICAL + HEALTH SERVICE	.00010	.00020	.00019	.00013	.00015	.00019	.00039	.00019	.00026	.00041	.00032	.00054	.00067
21.08 EDUCAT SERVC+NONPROF ORG	.00215	.00236	.00243	.00187	.00250	.00156	.00263	.00221	.00167	.00172	.00320	.00248	.00264
22.01 POST OFFICE	.00183	.00256	.00314	.00179	.00327	.00184	.00297	.00223	.00209	.00201	.00400	.00390	.00460
TOTAL	1.62172	1.72244	1.78042	1.59516	1.74770	2.25777	1.80166	1.81637	1.96126	1.86246	1.67332	1.72210	1.76133

TABLE 8. DIRECT AND INDIRECT EFFECTS, WORLD II

TABLE 9. SOCIAL SAVINGS

SOCIAL SAVINGS (MILLION 1976 DOLLARS)

	II	III	III-II
1.01 LIVESTK+LIVESTK PRODUCTS	422.77	211.04	211.73
1.02 FIELD + ORCHARD CROPS	394.06	197.44	196.61
1A03 FORESTRY PRODUCTS	6.05	3.29	2.76
1B03 FISHNG,HUNTNG,TRAPPING	20.66	6.93	13.73
1.04 AGRI, FORST + FISH SERVC	6.09	3.74	2.35
2.01 IRON + FERROALLOYS ORES	46.08	23.15	22.93
2X02 NONFERROUS ORES MINE	35.40	16.62	18.78
2A04 UNDERGROUND COAL MINE	212.58	-244.04	456.62
2B04 STRIP COAL MINING	59.48	30.25	29.23
2C04 OTHER COAL MINING	1.22	.59	.63
2A05 CRUDE PETROLEUM	850.74	355.51	495.23
2B05 NATURAL GAS	168.93	71.58	97.34
2.06 STONE + CLAY MINING	105.77	53.73	52.04
2.07 CHEM + FERTLZR MINERALS	14.59	6.32	8.27
3A01 BEVERAGES	1351.29	360.56	990.73
3B01 OTHER FOOD+KINDRED PRD	2583.42	1213.69	1369.72
3.02 TOBACCO MANUFACTURES	83.84	.46	83.37
3X03 LEATHR+LEATHR PRO	68.11	1.14	66.97
3X05 FAB,YARN,THRD+SFLOOR COV	990.33	-191.40	1181.73
3A07 METAL TIRE CORD	11.94	12.21	-.27
3B07 OTHER CORD+MISC TEXT PR	46.27	10.18	36.09
3X08 APPRL+MISC FAB TEXT PRD	234.37	92.13	142.24
4.01 SAWMILLS + PLANING MILLS	143.80	59.04	84.77
4.02 VENEER,PLYWOOD+LAM WD	213.11	90.58	122.53
4.03 OTHER LMBR+WD EX CONTNRS	196.77	72.16	124.61
4.04 WOODEN CONTAINERS	42.02	18.55	23.47
4XA5 WOOD FURNITUR+FIXTUR	482.37	208.53	273.83
4XB5 METAL FURNTR+FIXTURES	198.46	80.61	117.84
4.07 PULP+PAPR PRD EX CONTNRS	1249.53	564.08	685.45
4.08 PAPERBRD CONTAINERS+BOX	174.83	51.82	123.01
5.01 PETROL REFNG + RELTD PRD	1829.42	852.11	977.31
5.02 PAVING MIX+ASPHALT PRD	42.82	19.23	23.59
5.03 INDUSTRL INORG+ORG CHEM	1292.38	517.00	775.37
5X04 AGRICULTURAL CHEMICALS	79.47	22.44	57.02
5A06 ADHESIVES	116.28	43.50	72.78
5B06 OTHER CHEMICAL PRD	65.60	25.14	40.46
5.09 DRUGS	152.26	52.18	100.09
5X10 CLEANING+TOILET PREP	216.41	83.20	133.21
5.12 PAINTS+ALLIED PRD	134.25	60.19	74.06
P.07 PLAST MATR,RESIN+SYN RUB	84.64	15.02	69.62
P.08 ORGANIC MANMADE FIBERS	108.88	9.72	99.16
P.13 TIRES+INNER TUBES	1792.03	42.85	1749.18
PA14 INDUSTRIAL RUBBER BELTS	85.38	15.72	69.66
PB14 OTHER RUBBER PRD	138.04	36.24	101.80
PA15 PLASTIC PIPE	563.74	82.96	480.78
PB15 PLASTIC CONTAINERS	257.31	88.64	168.67
PC15 OTHER MANF PLASTIC PRD	431.11	150.58	280.52
6A01 FLAT GLASS	163.11	-6.40	169.51
6B01 GLASS CONTAINERS	497.50	56.65	440.85
6C01 AUTO+TRUCK WINDSHIELDS	35.03	3.13	31.90
6D01 OTHER GLASS PRD	177.42	29.67	147.75
6.02 CEMENT+LIME+GYPSUM PRD	57.90	22.79	35.11
6A03 STR CLAY PRD EX REFRAC	300.26	59.36	240.90
6B03 STR CONCRET PRD+CEMENT	815.12	228.36	586.76
6C03 POTRY+WHTWR+PORCLN PRD	100.80	27.89	72.91

TABLE 9. (Continued)

SOCIAL SAVINGS (MILLION 1976 DOLLARS)

	II	III	III-II
6003 CLAY+NCLAY REFRACTORIES	356.93	280.19	76.74
6A04 ABRASIVES INC GRIND WH	72.33	20.69	51.65
6B04 OTHER NONMET MINERAL PRO	58.47	22.54	35.92
7A01 IRON,CARBN STEEL+COKE	726.48	1220.66	-492.20
7B01 ALLOY STEEL	51.37	51.97	-.60
7C01 STAINLESS STEEL	27.61	23.79	3.82
7.03 PRIMARY ALUMINUM	304.83	209.71	95.13
7X04 OTHER NONFEROUS METALS	1863.15	969.72	893.44
8.01 METAL CANS	1032.51	392.12	640.39
8.02 METAL BARRELS,DRUM+PAILS	219.42	80.83	138.59
8.03 MET SANIT+PLUMBING PRO	32.57	5.34	27.24
8.04 NONELEC HEATING EQUIP	103.14	21.85	81.29
8A05 STRUCTURAL METAL	1815.04	685.90	1129.14
8B05 BOILER SHOP PRD	345.31	131.84	213.48
8C05 OTHER FAB STRUCTRL PRD	2205.87	842.44	1363.43
8.06 SCRW MACH PRD+STAMPNGS	1746.51	722.29	1024.22
8.07 FABRICATED METAL PRD	346.08	79.54	266.54
9.01 ENGINES + TURBINES	744.48	305.06	439.43
9.02 GEN INDUS MACH+EQUIP	1471.19	575.02	896.17
9.03 MACHINE SHOP PRO	298.43	112.82	185.62
10.01 FARM MACHINERY	409.53	158.31	251.22
10.02 CONSTRUCTION MACHINERY	1000.82	380.91	619.91
10.03 MINING MACHINERY	99.19	40.01	59.18
10.04 OIL FIELD MACHINERY	75.89	28.98	46.91
10.05 MTRL-HNDLNG MACH EX TRUC	457.51	176.88	280.64
10.06 INDUST TRUCKS + TRACTORS	177.65	66.07	111.58
10.07 METAL WORKING MACHINERY	479.42	182.50	296.93
10.08 SPECL INDSTRY MACHINERY	733.32	273.50	459.82
11.01 MOTOR VEHICLES + PARTS	9211.41	2682.24	6529.16
11.02 AIRCRAFT + PARTS	4940.66	27.10	4913.56
11.03 SHIP+BOAT BLDG + REPAIRS	430.38	76.79	353.60
11.04 LOCOMS+RAIL+RPD TRNST	359.85	143.86	215.99
11.05 CYCLES,TRAILERS, ETC	427.53	157.91	269.62
12.01 ELEC MEASURING INSTRUMTS	29.86	11.94	17.92
12A02 ELEC MOTRS+GENRTRS,POWPL	17.13	5.29	11.85
12B02 OTHER ELEC MOTRS+GENRTRS	325.96	114.08	211.89
12.03 INDUS CONTRL,TRANSFM,ET	97.40	10.29	87.10
12.04 ELECTRIC LAMPS	86.90	35.42	51.48
12.05 LIGHT FIXT+WIRING DEVICE	369.19	137.29	231.91
12.06 ELECTRNC COMPNTS+ACCESS	188.00	84.22	103.79
12A07 X-RAY EQUIPMENT	9.39	2.77	6.62
12B07 OTHER MISC ELEC MACH	202.23	73.30	128.92
13.01 SERVC INDUSTRY MACHINERY	606.07	210.47	395.59
13.02 HOUSEHOLD APPLIANCES	517.68	180.50	337.18
13.03 RADIO,TV+COMMUN EQUIP	292.91	53.54	239.38
14A01 FRACTURE CONTROL INSTR	24.61	-.51	25.12
14B01 OTHER SCNC INSTR,ETC	541.53	184.46	357.08
14.02 MED,SURGCL,DENTAL INSTR	136.25	42.22	94.03
14.03 WATCHES,CLOCKS + PARTS	31.75	9.34	22.42
14.04 OPTICAL+OPTHALMIC GOODS	55.85	24.52	31.33
14.05 PHOTO EQUIP + SUPPLIES	133.12	37.43	95.70
15.01 COMPUTING+RELAT MACHINES	163.20	66.22	96.98
15.02 OTHR OFFICE+BUSIN MACH	90.77	35.57	55.21
15.03 OFFICE SUPPLIES	26.32	12.16	14.17
16.01 ORDNANCE + ACCESSORIES	385.63	113.56	272.07

TABLE 9. (Continued)

SOCIAL SAVINGS (MILLION 1978 DOLLARS)

	II	III	III-II
16A02 SPORTING GOOD+TOYS	279.16	103.78	175.38
16B02 OTHER MISC PRD	198.90	63.97	134.93
17.01 RAILROADS+RELATD SERVCS	418.64	61.96	356.68
17.02 LOCAL+HIGHWAY PASSNGR TR	329.22	126.10	203.13
17.03 MOTOR FREIGHT+WAREHOUSE	492.69	186.76	305.92
17.04 WATER TRANSPORTATION	312.60	103.65	208.95
17.05 AIR TRANSPORT	647.31	68.87	578.43
17.06 PIPE LINES	27.00	10.09	16.91
17.07 TRANSPORTATION SERVICES	10.29	.07	10.21
18.01 TELECOMMUNICATION	121.63	46.20	75.43
18.02 ELECTRIC POWER	235.99	87.36	148.63
18.03 GAS	66.18	28.34	37.84
18.04 WATER + SANITARY SERVICE	36.24	3.04	33.20
19.01 NEW CONST,NONFARM RESID	4556.56	260.11	4296.45
19.02 CONST,NONRESID BUILD	2808.59	134.42	2674.17
19A03 CONST,RAILROADS	312.68	106.53	206.15
19B03 CONST, PIPELINES	87.97	31.14	56.83
19C03 OTHER PU, CONST	1783.67	513.76	1269.91
19A04 CONST,HIGHWAYS	504.27	-162.71	666.98
19B04 CONST,BRIDGES	168.97	47.10	121.87
19C04 CONST, DAMS	28.52	7.62	20.91
19D04 CONST, ALL OTHER	287.22	103.03	184.19
20.01 WHOLESALE+RETAIL TRADE	203.26	81.47	121.79
20XA2 INSURANCE	2.50	.92	1.58
20XB2 FINANC,REAL EST+ADVERTSG	143.29	-37.86	181.15
20A05 FRACT RESEAR+DEVEL	0.00	.56	-.56
20B05 OTHER RESEARCH + DEVEL	196.86	74.18	122.69
20C05 ENVIRONMENTAL CLEANUP	1.22	.43	.79
20D05 OTHR BUSNS+PROFESNL SERV	101.80	49.84	51.95
20.06 BUS TRAVEL,ENTER+GIFTS	4.08	2.06	2.02
21.01 PRINTING + PUBLISHING	246.65	122.19	124.46
21.02 RADIO + TV BROADCASTING	.04	.02	.02
21.03 HOTELS + LODGING PLACES	28.92	10.73	18.19
21A04 PERSONAL SERVICES	6.72	2.78	3.95
21B04 REPAIR SERV, EXC AUTO	6.38	2.55	3.83
21.05 AUTOMOBILE REPAIR+SERVC	564.24	283.24	281.00
21.06 AMUSEMENTS	23.36	7.44	15.92
21.07 MEDICAL + HEALTH SERVICE	48.50	20.22	28.28
21.08 EDUCAT SERVC+NONPROF ORG	52.02	1.04	50.97
22.01 POST OFFICE	25.96	10.70	15.26
23.01 SCRAP+SECOND-HAND GOODS	0.00	0.00	0.00
23.02 GOVERNMENT INDUSTRY	0.00	0.00	0.00
23.03 REST-OF-THE-WORLD INDUS	0.00	0.00	0.00
23.04 HOUSEHOLD INDUSTRY	0.00	0.00	-0.00
Total	72282.8	21075.8	51207.0

Returning now to our comparisons in terms of row 7A01 (iron and carbon steel) and column 11.01 (motor vehicles), suppose we examine the World II situation. In World II, the total output of iron/steel was $37.4 billion and that of motor vehicles was $141.6 billion (see Table 5). These were 57.5 percent and 97.8 percent of their respective World I values. Clearly, the total demand for iron/steel (a material) declined much more as a consequence of our no-fracture hypotheses than did the demand for motor vehicles (a finished artifact). With little change in the demand for vehicles, but with a significant reduction in the amount of iron/steel per vehicle, the World II dollar purchase of iron/steel (row 7A01) by motor vehicles (column 11.01) was $6.1 billion, less than half the $12.4 billion of World I (See Table 10). This cell accounts for 16 percent of the demand for iron/steel (down from 19 percent in World I) and for 4 percent of the inputs of motor vehicles (down from almost 9 percent in World I).

In aggregate terms, GNP (measured as total value added) in World II amounted to $2,165.7 billion (96.5 percent of the World I level). This may be viewed as one way of estimating the cost of fracture in the U.S. economy.

Model Outputs: World III

World III will be recalled as the hypothetical world that shows what our economy would have been if, in the real world of 1978, everyone had applied best fracture control practices. It must be emphasized that adjustments were made to World I data, not to those of World II, in order to establish the World III model.

Data Bases

The changes from World I to World II were much more uniform in nature and direction than were the corresponding changes to World III. In general, inputs would be reduced when going from a real world to a no-fracture situation. This would not necessarily be the case when going from the real world to a best practices situation. For instance, if supplier sectors all applied best practices, user sectors probably could reduce their inputs, though not by as much as would be true of World II. But if the user industry also must apply best practices, it may well tend to increase, rather than to reduce its inputs of certain resources. Moreover, if an industry in the real world is already at best practice, there would be no change between Worlds I and III with respect to the affected inputs.

Generally speaking, inputs were reduced in going from World I to World II. But, in going from World I to World III, they might be reduced by a lesser proportion, left unchanged, or even increased. Taken all together, about as many changes have been made in the A, B, R, and noncapital final demand data bases in generating World III as were made for World II.

The same metal input calculations that gave us standard 49 percent reductions in going to World II indicated that, given best practice conditions, metal inputs would be reduced by only 19 percent from World I

FRACTURE WORLD II PAGE 29

DOLLAR VALUES OF INTERINDUSTRY AND FINAL TRANSACTIONS (IN MILLIONS OF DOLLARS), UNITED STATES, 1978

	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02
6003 CLAY+NCLAY REFRACTORIE	0.0	.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5A04 ABRASIVES INC GRIND WH	66.3	22.5	242.6	93.4	33.3	0.0	117.4	0.0	2.4
6804 OTHER NONMET MINERAL P	28.4	9.6	161.7	93.4	33.3	0.0	50.3	0.0	1.5
7A01 IRON,CARBN STEEL+COKE	614.7	603.1	6119.5	89.2	128.5	287.9	134.7	.7	11.5
7801 ALLOY STEEL	25.9	35.5	257.7	63.0	5.4	12.1	5.7	1.3	1.5
7C01 STAINLESS STEEL	6.5	70.9	64.4	4.6	1.4	3.0	1.4	11.5	0.0
7.03 PRIMARY ALUMINUM	43.5	50.2	742.1	48.9	20.2	12.9	128.1	13.7	2.1
7X04 OTHER NONFEROUS METALS	116.4	111.7	342.8	123.3	68.8	.4	12.8	28.1	15.9
8.01 METAL CANS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.02 METAL BARRELS,DRUM+PAI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.03 MET SANIT+PLUMBING PRO	0.0	0.0	0.0	0.0	2.0	.7	62.5	0.0	0.0
8.04 NONELEC HEATING EQUIP	0.0	27.5	0.0	0.0	56.1	0.0	128.2	0.0	0.0
8A05 STRUCTURAL METAL	1.7	54.2	0.0	0.0	164.5	.0	7.0	0.0	0.0
LER SHOP PRO	5.7	162.6	0.0	0.0	54.8	.1	13.9	0.0	0.0
UCTRL PRO	4.0	144.5	0.0	0.0	54.8	.1	118.3	0.0	0.0
	93.4	60.3	5119.3	61.6	11.8	16.1	60.1	114.3	3.6
	43.2	232.8	2318.6	242.3	280.0	15.7	137.3	14.0	1.2
		1.0	372.8	6.6	381.4	66.0	0.0	0.0	.3
		523.3	1200.0	262.5	144.3	24.7	41.5	5.7	7.4
			2116.9	317.6	60.1	4.6	0.0	.3	.1
			0.0	0.0	0.0	0.0	0.0	0.0	0.0
				0.0	72.5	0.0	0.0	0.0	0.0
				0.0	0.0	0.0	0.0	0.0	0.0
19C0					0.0	0.0	0.0	0.0	0.0
19A04 CONST,HI					28.6	5.6	4.3	0.0	.0
19804 CONST,BRID						1.2	5.0	0.0	.0
19C04 CONST, DAMS						26.2	0.0	11.6	5.9
19D04 CONST, ALL OTHER						0.0	0.0	0.0	0.0
20.01 WHOLESALE+RETAIL TRADE	297.0						8.4	0.0	0.0
20XA2 INSURANCE	15.4						0.0	0.0	0.0
20X82 FINANC,REAL EST+ADVERT	261.7	231.1						0	0.0
20A05 FRACT RESEAR+DEVEL	0.0	0.0							0.0
20805 OTHER RESEARCH + DEVEL	187.0	256.0	2917.3						0
20C05 ENVIRONMENTAL CLEANUP	0.0	0.0	0.0	0.0					
20005 OTHR BUSNS+PROFESNL SE	68.6	119.0	203.8	132.3					
20.06 BUS TRAVEL,ENTER+GIFTS	135.3	100.2	98.5	208.7	30.2				
21.01 PRINTING + PUBLISHING	.7	2.1	0.0	31.6	5.6				
21.02 RADIO + TV BROADCASTIN	0.0	0.0	0.0	0.0	0.0	0.0			
21.03 HOTELS + LODGING PLACE	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
21A04 PERSONAL SERVICES	7.6	3.3	5.3	0.0	0.0	0.0	0.0		
21804 REPAIR SERV, EXC AUTO	6.8	3.0	4.7	0.0	21.7	0.0	1.5	2.2	
21.05 AUTOMOBILE REPAIR+SERV	6.8	4.4	2680.1	3.4	8.6	2.5	1.6	3.8	
21.06 AMUSEMENTS	.4	0.0	0.0	0.0	.1	.0	.2	.1	0.0
21.07 MEDICAL + HEALTH SERVI	0.0	0.0	0.0	6.2	.5	.3	2.2	.7	.1
21.08 EDUCAT SERVC+NONPROF O	14.6	21.2	48.2	42.7	9.5	2.2	5.2	9.6	.4
22.01 POST OFFICE	9.1	25.9	40.2	48.1	6.1	2.0	4.7	11.8	.9
23.01 SCRAP+SECOND-HAND GOOD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.02 GOVERNMENT INDUSTRY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.03 REST-OF-THE-WORLD INDU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.04 HOUSEHOLD INDUSTRY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.00 DOMESTIC INTERMT INPUT	4178.6	5364.2	83734.9	14324.1	3355.2	1621.0	3807.1	1601.6	122.5
25.00 DOMESTIC VALUE ADDED	8000.0	7328.6	26674.7	12939.9	4269.7	1256.0	3192.2	3396.4	215.4
26.00 TOTAL IMPORTS	2118.7	940.2	21932.7	1007.1	201.3	175.9	1637.0	0.0	0.0
27.00 SOCIAL SAVINGS/COST	479.4	733.3	9211.4	4940.7	430.4	359.8	427.5	29.9	17.1
28.00 TOTAL INPUT/OUTPUT	14776.7	14366.3	141553.8	33211.7	8256.6	3412.7	9063.8	5027.9	355.0

TABLE 10. DOLLAR VALUES OF INTERINDUSTRY AND FINAL TRANSACTIONS, WORLD II

levels. It will be recalled that iron and steel input into motor vehicles (row 7A01 and column 11.01) had the direct technical coefficient of 0.08562 in World I and 0.04323 in World II. In World III, this coefficient would be 0.07327 (see Table 11). The World I/III difference (.08563-.07327 = .01235) would be entered as a social saving in column 11.01. However, as was true in World II, there have been other adjustments in motor vehicle technology, so that the net social saving is shown as 0.01871 (Table 11).

Since changes can be made in either direction in going from the real to the best practices situation, it is possible for some sectors to show social costs (with a minus sign) in this row. This is true, for example, of sector 2A04 (Underground Coal Mining) because best practices would involve substantial increases in the use of roof bolts. It is also true of sector 3X05 (Fabrics, Yarns, Threads, and Soft Floor Coverings) which would use more fiber. Other sectors showing social costs in World III (see Table 9) are:

6A01, Flat Glass
14A01, Fracture Control Instruments
19A04, Construction, Highways
20XB2, Finance, Real Estate and Advertising.

Calculated Outputs

Generally speaking, the calculated changes in World III will not be as greatly different from World I as are those in World II. Taking the inverse of the cell for row 7A01 and column 11.01 as an example, it will be recalled that for World I it was 0.18840, and for World II it was 0.0990; the World III value is 0.15871 (see Table 12).

The Transactions Table. Using the same examples as before, World III total outputs for iron/steel is estimated to be $54.2 billion; and for motor vehicles it is estimated to be $143.4 billion (see Table 5). These are 83 percent and 99 percent of the corresponding World I values, respectively. Iron/steel input into motor vehicles was $10.5 billion, 84 percent of the World I value (see Table 13). This cell accounts for 19 percent of iron/steel output and 7 percent of motor vehicle inputs.

In aggregate terms, World III GNP (measured as total industrial value added) is estimated to be $2,220.7 billion, 99.0 percent of World I.

The above examples, stressing the relations between Sector 7A01, as a row, and Sector 11.01 as a column, are illustrative of the entire set of possible interactions and their implications.

Model Outputs: The Difference Tables

There are many aspects of the costs of fracture that can be clarified by discussions and computation such as those above. It will be noted that many of these discussions have involved calculations of the differences among World I, II and III values. For convenience, Appendix H includes, in addition

FRACTURE WORLD III PAGE 20

DIRECT TECHNICAL COEFFICIENTS, UNITED STATES 1978

	10.04	10.05	10.06	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02	12B02
6D03 CLAY+NCLAY REFRACTORIES	0.00000	0.00000	0.00000	0.00000	.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6A04 ABRASIVES INC GRIND WH	.00010	0.00000	0.00000	.00451	.00157	.00172	.00281	.00404	0.00000	.01302	0.00000	.00676	.00825
6B04 OTHER NONMET MINERAL PRD	.00007	0.00000	0.00000	.00193	.00067	.00115	.00281	.00404	0.00000	.00558	0.00000	.00422	.00183
7A01 IRON,CARBN STEEL+COKE	.07663	.06861	.09173	.05017	.05759	.07327	.00086	.02629	.13467	.02371	.00021	.05166	.05571
7B01 ALLOY STEEL	.00323	.00289	.00386	.00211	.00339	.00308	.00729	.00111	.00567	.00100	.00043	.00684	.01114
7C01 STAINLESS STEEL	.00081	.00072	.00097	.00053	.00678	.00077	.00043	.00028	.00142	.00025	.00362	0.00000	0.00000
7.03 PRIMARY ALUMINUM	.00087	.00290	.00348	.00355	.00480	.00888	.00421	.00413	.00601	.02256	.00434	.00924	.00891
7X04 OTHER NONFEROUS METALS	.00212	.00325	.00474	.00950	.01067	.00410	.02651	.01408	.00020	.00225	.00558	.04477	.04677
8.01 METAL CANS	.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8.02 METAL BARRELS,DRUM+PAILS	.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8.03 MET SANIT+PLUMBING PRD	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.00024	.00022	.00693	0.00000	0.00000	0.00000
8.04 NONELEC HEATING EQUIP	0.00000	0.00000	0.00000	0.00000	.00192	0.00000	0.00000	.00680	0.00000	.01421	0.00000	0.00000	0.00000
AL METAL	0.00000	.00040	0.00000	.00012	.00379	0.00000	0.00000	.01995	.00001	.00077	0.00000	0.00000	0.00000
PRD	0.00000	.00064	0.00000	.00039	.01137	0.00000	0.00000	.00665	.00003	.00154	0.00000	0.00000	0.00000
UCTRL PRD	0.00000	.00056	0.00000	.00027	.01011	0.00000	0.00000	.00665	.00004	.01312	0.00000	0.00000	0.00000
	0864	.00534	.02753	.00635	.00422	.03635	.01855	.00143	.00473	.00667	.02273	.01014	.01284
		.00914	.00079	.00294	.01629	.01646	.00730	.03396	.00461	.01522	.00279	.00338	.00459
		.00053	.04058	0.00000	.00007	.00266	.00020	.04648	.01954	0.00000	0.00000	.00084	.00046
				.02123	.03679	.00856	.00794	.01759	.00730	.00463	.00114	.02101	.02738
				.00112	.00255	.01511	.00961	.00733	.00137	0.00000	.00006	.00017	.00009
				0000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
					0.00000	0.00000	0.00000	.00928	0.00000	0.00000	0.00000	0.00000	0.00000
1							0000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19A0							00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19B04 CONST,BRI							0.00000	.00366	.00174	.00051	0.00000	.00004	.00013
19C04 CONST, DAMS								51	.00039	.00059	0.00000	.00008	.00017
19D04 CONST, ALL OTHER										00000	.00233	.01681	.01825
20.01 WHOLESALE+RETAIL TRADE	.01354									000	0.00000	0.00000	.00004
20XA2 INSURANCE	.00023	.00								71	0.00000	0.00000	0.00000
20XB2 FINANC,REAL EST+ADVERTSG	.00961	.0120										0000	0.00000
20A05 FRACT RESEAR+DEVEL	.00043	.00078	.00096	.00								00	0.00000
20B05 OTHER RESEARCH + DEVEL	.01021	.03805	.03106	.01272									
20C05 ENVIRONMENTAL CLEANUP	0.00000	0.00000	0.00000	0.00000	0.00000	0.0							
20D05 OTHR BUSNS+PROFESNL SERV	.00650	.00432	.00378	.00467	.00833	.001							
20.06 BUS TRAVEL,ENTER+GIFTS	.00793	.00388	.00732	.00920	.00701	.00070	.00628						
21.01 PRINTING + PUBLISHING	.00008	0.00000	.00012	.00005	.00015	0.00000	.00095	.000					
21.02 RADIO + TV BROADCASTING	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	00000	0.			
21.03 HOTELS + LODGING PLACES	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.000			
21A04 PERSONAL SERVICES	0.00000	0.00000	0.00000	.00052	.00023	.00004	0.00000	0.00000	0.00000	0.00000			
21B04 REPAIR SERV, EXC AUTO	.00063	.00014	.00024	.00049	.00022	.00004	0.00000	.00277	0.00000	.00018	.00047	.00	
21.05 AUTOMOBILE REPAIR+SERVC	.00071	.00129	.00145	.00046	.00031	.01909	.00010	.00105	.00073	.00018	.00076	.00042	
21.06 AMUSEMENTS	.00004	0.00000	0.00000	.00002	0.00000	0.00000	0.00000	.00002	.00001	.00002	.00002	0.00000	0.00000
21.07 MEDICAL + HEALTH SERVICE	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.00019	.00006	.00010	.00025	.00014	.00034	.00046
21.08 EDUCAT SERVC+NONPROF ORG	.00134	.00131	.00135	.00099	.00148	.00034	.00128	.00116	.00066	.00057	.00190	.00127	.00138
22.01 POST OFFICE	.00080	.00121	.00159	.00062	.00182	.00029	.00145	.00074	.00058	.00052	.00234	.00253	.00321
23.01 SCRAP+SECOND-HAND GOODS	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.02 GOVERNMENT INDUSTRY	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.03 REST-OF-THE-WORLD INDUS	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23.04 HOUSEHOLD INDUSTRY	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24.00 DOMESTIC INTERMT INPUT	.35532	.40010	.43800	.29671	.39942	.63312	.49615	.43137	.53509	.44438	.32217	.37290	.39282
25.00 DOMESTIC VALUE ADDED	.62045	.57656	.33771	.54839	.51672	.19323	.47272	.53511	.37381	.35773	.67551	.61232	.52510
26.00 TOTAL IMPORTS	0.00000	0.00000	.20227	.14338	.06545	.15494	.03032	.02438	.05155	.18061	0.00000	0.00000	.06287
27.00 SOCIAL SAVINGS/COST	.02423	.02333	.02202	.01152	.01842	.01871	.00080	.00913	.03956	.01729	.00232	.01479	.01920
28.00 TOTAL INPUT/OUTPUT	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

TABLE 11. DIRECT TECHNICAL COEFFICIENTS, WORLD II

WORLD III PAGE 20

DIRECT AND INDIRECT EFFECTS, UNITED STATES, DYNAMIC, 1978

	10.04	10.05	10.06	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02	12802
6003 CLAY+NCLAY REFRACTORIES	.00520	.00492	.00608	.00359	.00462	.00698	.00178	.00310	.00947	.00260	.00118	.00415	.00469
6A04 ABRASIVES INC GRIND WH	.00107	.00140	.00170	.00610	.00322	.00458	.00494	.00622	.00171	.01635	.00103	.00850	.01021
6804 OTHER NONMET MINERAL PRD	.00088	.00098	.00118	.00321	.00188	.00325	.00448	.00556	.00133	.00815	.00069	.00567	.00344
7A01 IRON,CARBN STEEL+COKE	.12191	.11168	.14000	.07845	.10070	.15871	.02078	.06524	.22268	.05404	.01621	.08115	.08927
7801 ALLOY STEEL	.00470	.00464	.00572	.00317	.00534	.00625	.01088	.00292	.00894	.00197	.00129	.00838	.01327
7C01 STAINLESS STEEL	.00140	.00144	.00172	.00152	.00922	.00237	.00138	.00143	.00248	.00120	.00467	.00046	.00050
7.03 PRIMARY ALUMINUM	.00506	.00917	.01076	.00910	.01450	.02670	.01267	.01399	.01700	.04264	.01098	.01849	.01847
7X04 OTHER NONFEROUS METALS	.00874	.01284	.01556	.01874	.02209	.01887	.04625	.02625	.01298	.01131	.01586	.06105	.06405
8.01 METAL CANS	.00020	.00022	.00020	.00027	.00020	.00027	.00020	.00027	.00033	.00040	.00025	.00039	.00043
8.02 METAL BARRELS,DRUM+PAILS	.00019	.00025	.00022	.00015	.00024	.00036	.00022	.00062	.00036	.00035	.00029	.00035	.00041
8.03 MET SANIT+PLUMBING PRO	.00016	.00021	.00020	.00022	.00022	.00023	.00015	.00044	.00047	.00765	.00026	.00018	.00018
8.04 NONELEC HEATING EQUIP	.00037	.00054	.00049	.00050	.00264	.00056	.00037	.00744	.00047	.01572	.00057	.00044	.00046
TURAL METAL	.00137	.00227	.00180	.00190	.00610	.00197	.00137	.02206	.00187	.00251	.00199	.00167	.00171
OP PRO	.00094	.00179	.00109	.00141	.01346	.00128	.00083	.00818	.00123	.00286	.00114	.00105	.00111
TRUCTRL PRO	.00266	.00404	.00328	.00364	.01454	.00391	.00235	.01003	.00370	.01694	.00380	.00303	.00313
	.01111	.00785	.03066	.00883	.00652	.05561	.02677	.00496	.00857	.01118	.02849	.01233	.01513
	.02365	.01389	.00525	.00653	.02223	.03047	.01498	.04124	.00966	.02465	.00881	.00760	.00912
	[illegible]	.00173	.04559	.00099	.00125	.00575	.00113	.05280	.02751	.00128	.00084	.00226	.00188
		[illegible]	.03790	.02803	.04710	.02002	.01471	.02536	.01615	.01082	.00579	.02724	.03453
			.02578	.00173	.00361	.02439	.01467	.01073	.00344	.00156	.00054	.00095	.00085
				[illegible]	.00011	.00015	.00010	.00012	.00011	.00026	.00012	.00019	.00021
					.00165	.00222	.00115	.01111	.00250	.00147	.00117	.00180	.00189
					[illegible]	.00135	.00052	.00077	.00171	.00065	.00036	.00102	.00109
							.00014	.00020	.00024	.00019	.00014	.00017	.00016
17.07 TR							.00365	.00759	.00666	.00533	.00393	.00380	.00405
18.01 TELE								[illegible]	.00120	.00123	.00050	.00055	.00066
18.02 ELECTRI									.02338	.01246	.01623	.02775	.02974
18.03 GAS									.00357	.00354	.00321	.00273	.00306
18.04 WATER + SANITARY SERVIC										[illegible]	.00600	.00690	.00716
19.01 NEW CONST,NONFARM RESID	[illegible]	[illegible]									.00073	.00111	.00118
19.02 CONST,NONRESID BUILD	.02592	[illegible]									[illegible]	.00036	.00038
19A03 CONST,RAILROADS	.00083	.00100											.00091
19803 CONST, PIPELINES	.00008	.00006	.00007	[illegible]									[illegible]
19C03 OTHER PU, CONST	.00316	.00366	.00440	.00339									
19A04 CONST,HIGHWAYS	.00026	.00023	.00029	.00024	[illegible]	[illegible]							
19804 CONST,BRIDGES	.00001	.00001	.00001	.00001	.00001	.00002							
19C04 CONST, DAMS	.00001	.00001	.00001	.00001	.00001	.00001							
19004 CONST, ALL OTHER	.00066	.00054	.00068	.00058	.00080	.00064	.00054	[illegible]					
20.01 WHOLESALE+RETAIL TRADE	.02312	.01693	.04408	.03059	.03178	.02865	.02964	.04871					
20XA2 INSURANCE	.00186	.00357	.00411	.00305	.00307	.00455	.00294	.00296		[illegible]			
20X82 FINANC,REAL EST+ADVERTSG	.02361	.02699	.04493	.03261	.03401	.03156	.02585	.02652	.03185	.03260			
20A05 FRACT RESEAR+DEVEL	.00062	.00103	.00121	.00042	.00057	.00088	.00335	.00067	.00027	.00048			
20805 OTHER RESEARCH + DEVEL	.01742	.05146	.04226	.02037	.02784	.04170	.04760	.02347	.01279	.02238	[illegible]	[illegible]	
20C05 ENVIRONMENTAL CLEANUP	.00018	.00016	.00021	.00016	.00023	.00021	.00017	.00024	.00029	.00021	.00016	.00020	[illegible]
20005 OTHR BUSNS+PROFESNL SERV	.01207	.01101	.01187	.01050	.01536	.01005	.01110	.01544	.00954	.01228	.01119	.01169	[illegible]
20.06 BUS TRAVEL,ENTER+GIFTS	.01286	.01100	.01420	.01438	.01330	.00823	.01463	.01071	.01340	.02547	.01916	.04015	.04336
21.01 PRINTING + PUBLISHING	.00201	.00317	.00338	.00199	.00259	.00269	.00483	.00332	.00222	.00242	.01233	.00293	.00310
21.02 RADIO + TV BROADCASTING	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00005
21.03 HOTELS + LODGING PLACES	.00131	.00123	.00148	.00148	.00138	.00087	.00151	.00124	.00153	.00262	.00202	.00839	.00912
21A04 PERSONAL SERVICES	.00007	.00008	.00012	.00065	.00035	.00014	.00011	.00010	.00011	.00012	.00061	.00025	.00027
21804 REPAIR SERV, EXC AUTO	.00091	.00037	.00054	.00074	.00051	.00037	.00026	.00322	.00033	.00059	.00079	.00132	.00135
21.05 AUTOMOBILE REPAIR+SERVC	.00226	.00313	.00399	.00213	.00217	.02947	.00204	.00336	.00312	.00344	.00302	.00301	.00315
21.06 AMUSEMENTS	.00027	.00028	.00036	.00038	.00033	.00022	.00036	.00031	.00037	.00064	.00050	.00092	.00100
21.07 MEDICAL + HEALTH SERVICE	.00011	.00021	.00021	.00013	.00016	.00021	.00041	.00020	.00029	.00042	.00032	.00055	.00068
21.08 EDUCAT SERVC+NONPROF ORG	.00222	.00243	.00250	.00191	.00256	.00166	.00277	.00227	.00177	.00179	.00322	.00254	.00270
22.01 POST OFFICE	.00193	.00268	.00327	.00185	.00337	.00201	.00318	.00233	.00228	.00211	.00403	.00400	.00472
TOTAL	1.71495	1.81674	1.87676	1.64038	1.82697	2.41546	1.96789	1.89877	2.13380	1.94716	1.70091	1.80553	1.85383

TABLE 12. DIRECT AND INDIRECT EFFECTS, WORLD III

FRACTURE WORLD III PAGE 29

DOLLAR VALUES OF INTERINDUSTRY AND FINAL TRANSACTIONS (IN MILLIONS OF DOLLARS), UNITED STATES, 1978

	10.07	10.08	11.01	11.02	11.03	11.04	11.05	12.01	12A02
6003 CLAY+NCLAY REFRACTORIE	0.0	.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6A04 ABRASIVES INC GRIND WH	71.4	23.3	247.0	95.3	33.9	0.0	118.9	0.0	2.4
6B04 OTHER NONMET MINERAL P	30.6	10.0	164.6	95.3	33.9	0.0	51.0	0.0	1.5
7A01 IRON,CARBN STEEL+COKE	794.9	855.1	10504.1	29.1	221.0	489.8	216.6	1.1	18.5
7B01 ALLOY STEEL	33.5	50.3	442.3	247.0	9.3	20.6	9.1	2.2	2.4
7C01 STAINLESS STEEL	8.4	100.6	110.6	14.5	2.3	5.2	2.3	18.6	0.0
7.03 PRIMARY ALUMINUM	56.3	71.2	1273.8	142.5	34.7	21.9	206.1	22.3	3.3
7X04 OTHER NONFEROUS METALS	150.5	158.4	588.4	897.8	118.4	.7	20.6	28.7	16.0
8.01 METAL CANS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.02 METAL BARRELS,DRUM+PAI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.03 MET SANIT+PLUMBING PRD	0.0	0.0	0.0	0.0	2.0	.8	63.3	0.0	0.0
8.04 NONELEC HEATING EQUIP	0.0	28.6	0.0	0.0	57.2	0.0	129.8	0.0	0.0
8A05 STRUCTURAL METAL	1.8	56.3	0.0	0.0	167.8	.0	7.0	0.0	0.0
...ILER SHOP PRD	6.1	168.9	0.0	0.0	55.9	.1	14.1	0.0	0.0
...STRUCTRL PRD	4.3	150.1	0.0	0.0	55.9	.2	119.8	0.0	0.0
...NGS	100.7	62.6	5211.1	628.1	12.0	17.2	60.9	116.9	3.6
	46.6	241.8	2360.2	247.1	285.5	16.8	139.0	14.4	1.2
	0.0	1.0	381.4	6.7	390.8	71.1	0.0	0.0	.3
		546.3	1227.7	269.0	147.9	26.5	42.2	5.9	7.5
		[illegible]	2165.7	325.5	61.6	5.0	0.0	.3	.1
			0.0	0.0	0.0	0.0	0.0	0.0	0.0
			0.0	0.0	78.0	0.0	0.0	0.0	0.0
				0.0	0.0	0.0	0.0	0.0	0.0
19C03					0.0	0.0	0.0	0.0	0.0
19A04 CO…						6.3	4.6	0.0	.0
19B04 CONST,…						1.4	5.4	0.0	.0
19C04 CONST, DAMS							0.0	12.0	6.0
19D04 CONST, ALL OTHER							0.0	0.0	0.0
20.01 WHOLESALE+RETAIL TRADE	[illegible]							0.0	0.0
20XA2 INSURANCE	16.6							0.0	0.0
20XB2 FINANC,REAL EST+ADVERT	282.1	[illegible]							0.0
20A05 FRACT RESEAR+DEVEL	4.1	5.4							
20B05 OTHER RESEARCH + DEVEL	201.6	265.9	[illegible]						
20C05 ENVIRONMENTAL CLEANUP	0.0	0.0	0.0						
20D05 OTHR BUSNS+PROFESNL SE	74.0	123.7	207.5	134.9					
20.06 BUS TRAVEL,ENTER+GIFTS	145.8	104.0	100.3	212.8	[illegible]				
21.01 PRINTING + PUBLISHING	.8	2.2	0.0	32.2	5.7				
21.02 RADIO + TV BROADCASTIN	0.0	0.0	0.0	0.0	0.0	0.0			
21.03 HOTELS + LODGING PLACE	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]		
21A04 PERSONAL SERVICES	8.2	3.5	5.4	0.0	0.0	0.0	0.0	[illegible]	
21B04 REPAIR SERV, EXC AUTO	7.8	3.3	5.1	C.0	23.3	0.0	1.6	2.4	[illegible]
21.05 AUTOMOBILE REPAIR+SERV	7.3	4.6	2736.3	3.4	8.8	2.7	1.6	3.9	.2
21.06 AMUSEMENTS	.4	0.0	0.0	0.0	.1	.1	.2	.1	0.0
21.07 MEDICAL + HEALTH SERVI	0.0	0.0	0.0	6.3	.5	.4	2.3	.7	.1
21.08 EDUCAT SERVC+NONPROF O	15.7	22.0	49.0	43.5	9.7	2.4	5.2	9.8	.5
22.01 POST OFFICE	9.8	27.0	40.9	49.1	6.2	2.1	4.7	12.0	.9
23.01 SCRAP+SECOND-HAND GOOD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.02 GOVERNMENT INDUSTRY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.03 REST-OF-THE-WORLD INDU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.04 HOUSEHOLD INDUSTRY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.00 DOMESTIC INTERMT INPUT	4701.5	5930.2	90768.4	16802.8	3626.6	1946.1	4058.6	1657.4	133.3
25.00 DOMESTIC VALUE ADDED	8689.4	7671.8	27702.6	16009.3	4498.8	1359.6	3267.2	3475.2	218.9
26.00 TOTAL IMPORTS	2271.9	971.7	22213.6	1026.9	205.0	187.5	1549.5	0.0	0.0
27.00 SOCIAL SAVINGS/COST	182.5	273.5	2682.2	27.1	76.8	143.9	157.9	11.9	5.3
28.00 TOTAL INPUT/OUTPUT	15845.4	14847.1	143366.9	33866.1	8407.2	3637.0	9133.2	5144.5	357.5

TABLE 13. DOLLAR VALUES OF INTERINDUSTRY AND FINAL TRANSACTIONS, WORLD II

to the referenced tables, three so-called "difference" tables. These tables are derived from the three transactions tables in the following manner and are associated with the following cost-of-fracture concepts:

- Total Cost-of-Fracture Table is obtained by subtracting every cell in the World II table from the corresponding cell in the World I table.

- The Presently Reducible Cost-of-Fracture Table is obtained by subtracting every cell in the World III table from the corresponding cell in the World I table.

- The Presently Nonreducible Cost-of-Fracture Table is obtained by subtracting every cell in the World II table from the corresponding cell in the World III table.

Interpreting the Tables

In these tables, positive and negative values must be interpreted very carefully. One set of interpretations applies everywhere except the Social Savings/Cost row. This row is particularly important to measurements of the cost of fracture, and should be viewed in isolation.

General Interpretation. If the dollar value in a given cell in the World I table is larger than the corresponding value in the World II or III, the values of that cell in the difference table will be positive (i.e., will be shown with no sign). If the reverse is true, the cell in the difference table will show a negative value (i.e., have a minus sign). These relationships are to be interpreted in the usual manner. A positive cell value in the World I-World II table indicates that the input or output is higher in World I and is reduced as we shift to World II conditions. Thus, a positive cell value would indicate a saving (a reduction in resource use) in moving from World I to World II, from World I to World III, and from World III to World II. A negative cell value would mean just the opposite.

Interpretation of Social Saving/Cost Row. This row tends to take the opposite sign from other rows in the matrix. For example, if every input in a column is reduced in going from World I or World III conditions to World II conditions, the World II social savings entry, unlike those above it, will be bigger than the corresponding World I and III values.* Thus, the corresponding value in the difference table will be negative. In other words, an entry on the Social Saving/Cost row in the difference table must be interpreted in the opposite direction to its sign, when compared either to other rows in the difference table or to the Social Saving/Cost row in the transaction table for

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* The reader is reminded that, in World I, every social saving entry, by definition, is zero.

a single World. A minus sign on this row of the difference table means a social saving--that is, comparative reduction in the use of resources--while a plus sign means a social cost, a comparative increase in the use of resources.

The World I-World II Difference Table

This is the key table for measurement of the total cost of fracture in the U.S. The only element in total fracture cost that is not included in this table is the very small sum, generated by the Supplemental Models, that will be added in Chapter VIII.

The total cost of fracture, in terms which involve no double counting and are directly comparable with GNP, is obtained by summing across the Social Saving/Cost row of the World I-World II difference table. The resources saved in the productive process are summed when the Total Intermediate Output (TIO) column intersects the social saving row. They amount to $72.3 billion. The final demand reductions save an additional $14.2 billion (shown in this same row in the Total Final Demand, TFD, column). All together, this totals to $86.5 billion, or 3.9 percent of World I GNP ($2,243.0 billion). This implies that, in the complete absence of fracture within design, as hypothesized for World II, we would have an additional 3.9 percent of GNP, now diverted to the prevention or offsetting of fracture, available for other uses.

If desired, the use of this table permits breaking the $86.5 billion cost of fracture into the contributions of particular markets or technologies. For instance, $9.2 billion results from resources saved by the motor vehicles sector, of which $6.3 billion is saved in the form of reduced iron and carbon steel inputs.* We can also go over to the final demand side of the table and say that, of the $14.2 billion saved by no-fracture reductions in demand, $3.5 billion are accounted for by reductions in consumption, and $289 million of that comes about through reduced purchases of motor vehicles.**

A further step can also be taken in analyzing these savings. In addition to reduced direct purchase of cars, trucks and parts from sector 11.01, consumers also reduced their use of auto repair and services (sector 21.05) by $185.7 million. Sector 21.05 also purchases motor vehicles and parts (row 11.01, column 21.05) and these purchases were reduced by $629 million. This type of back-tracing can be carried as far as anyone needs or desires.

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* The $9.2 billion appear (with a minus sign) in the Social Savings/Cost row for column 11.01. If we go up that column to the 7A01 row, we find the $6.3 billion (as a positive entry).

** The $3.5 billion is the Social Savings/Cost entry in the Personal Consumption Expenditure (PCE) column. Reading up that column to row 11.01, we find $288.9 million.

The World I-World III Difference Table

Just as the World I-World II table allows the evaluation of total costs of fracture, the World I-World III table allows the evaluation of the presently reducible costs. These costs are $21.1 billion from TIO and $4.6 billion from TFD for a total of $25.7 billion. This tells us that, if we put into practice all we now know about fracture control and prevention, we could save almost 30 percent of the total resources currently lost to fracture. The remaining 70 percent of those costs are currently nonreducible and, by definition, none of the resources which they represent could be saved until future research and development activities have improved on present best practices.

Other analyses and tracings of costs can be carried out with this table, just as they were with the World I-World II table. However, there is no need to pursue the analysis until a later chapter.

The World III-World II Difference Table

Just as the World I-World II table describes total costs of fracture and the World I-World III table describes the presently reducible costs, this table describes the presently nonreducible costs--that 70 percent which cannot be affected by present best practices. There is no need to undertake any further numerical analyses of this table at present, since all three tables are structurally similar.

It is very important, however, to point out that this World III-World II table sets out many of the elements which must be taken into account if we are to plan well for future R&D directed toward fracture reduction and control. The amounts of benefit that can be gained by successful R&D in various directions fall within the limits indicated in this table.

For instance, the most that we can hope to save by improved fracture related practices in the manufacture of motor vehicles cannot exceed $2.7 billion (the Social Savings/Cost entry in column 11.01), but there are no other sectors which offer as much potential direct saving. However, if R&D effort is directed toward improving the material qualities of iron/steel, the potential economy-wide savings in resources could be as much as $10.8 billion (the TO entry on the 7A01 row).

In Chapter VII, we take up some of the potential savings that can accrue to the national economy through future R&D. These so-called "future reducible costs of fracture" represent a very important purpose for which this study was undertaken. It is interesting to note that potential savings with respect to fracture include both the presently reducible and the future reducible costs. The discussion of Chapter VII can be anticipated to the extent of pointing out that both are substantial. However, while savings via presently reducible costs require education and technology transfer, savings via future reducible costs require R&D, additional education, and additional transfers of the yet-to-be-developed technologies.

VI. SUPPLEMENTAL MODELS

The calibration of the Supplemental Models involved the collection and assimilation of substantial bodies of data. The general procedures and steps followed in the process of arriving at final cost estimates are presented below. Details of the Supplemental Model methodologies and assumptions that had to be made for their use in this study are provided in Appendix E.

Data

The most critical feature of the data sets assembled to run the Supplemental Models was their highly variable level of detail. For example, industries monitored by government agencies or which are more highly regulated had much useful, detailed information on the number of accidents of given types as well as the causes and consequences of those accidents; this was not the case for the nonregulated, nonmonitored industries. For these latter, problems of nonreporting, partial reporting, and questionable or misleading reporting created substantial difficulty in the use of available data. The extreme variability in the data resulted in having to make more simplifying assumptions than originally anticipated in screening the events data (as documented in Appendix E). While the degree of assumption required for estimation of different events data was directly related to the degree to which data were available, it is felt that, even in cases where minimal data were available, reasonably accurate estimates have been made.

Generally, data were collected from a variety of government and industry reports, academic sources, interviews with public and private officials, and through numerous telephone contacts (a complete list of references appear in Appendix E.)

In structuring the data, accidents were divided into classes of events (See Table 14). Events were chosen after trying to strike a balance between types of data available and breadth of coverage of fracture-caused incidents. It is noted that, even within a class of events, extreme variability in data detail was found. For example, railroad data provided information on the types of injuries that resulted from fracture, while marine data only permitted estimates of the total number of injuries. In the latter case, costs were calculated in terms of an average marine accident injury, rather than for specific types of injuries. Similarly, as information on specific property that was damaged was often not available, total property damage cost estimates were made, where appropriate. Environmental degradation information was even scarcer, which necessitated the positing of even further levels of assumptions, the details of which also appear in Appendix E.

The remainder of this chapter discusses two techniques utilized to supplement the direct data that were gathered: the maximum/minimum approach, and the translation of findings between types or groups of events. In these ways, order-of-magnitude estimates were produced for fracture events, as presented in the final section of this chapter.

TABLE 14. LIST OF EVENTS

Accident Type	Events
Transportation-Related	Railroad Pipelines Auto Other motor vehicle Air Transport Marine
Work-Related	Construction Agriculture Mining Manufacturing
Home-Related	Home Product Failure Houses
Public-Related	Utilities Public Structures
Other	Military Communications-related Medical-related Storage-related Recreation-related

Maximum/Minimum Approach

The lack of specificity in much of the available data required that an approximation be used to set ranges on the numbers of events which were appropriate to the study. In the examination of the records of any single type of event, the basic concept of Scope provided some guidance in selecting maximum and minimum numbers of these events. To the extent supported by notes on investigations or assignments of responsible causative factors, a single class of events could be examined to estimate:

(1) that fraction which were clearly identified with material or component fracture--thereby providing a minimum percent of such events which needed to be included in the analysis; and

(2) that fraction which were clearly identified as being caused by factors other than fracture--thereby establishing a maximum percent of such events which should be included.

The level of detail relative to any one class of events varied considerably among the different sources of data. However, selected sources were sufficiently documented such that further refinement of the maximum percent could be achieved; that is, considerations of fracture within scope could be applied, thereby reducing the maximum percent and narrowing the range of events which were germane to this study.

Minimum and maximum estimates were applied in all the supplemental models. When data deficiencies required making an assumption regarding the percentage of a given type of event that was caused by fracture within scope, both upper and lower bound estimates for this percentage were made, utilizing percentages from other events. Later, when estimating costs associated with property damage in this same event, maximum and minimum cost estimates were again established. All lower estimates were then multiplied together to provide a minimum cost for this event. Similarly, all higher estimates were multiplied together to produce the maximum cost for this event. This range was then included in the results.

This method, while not exact, is responsive to the needs of this study for three reasons. First, since the data are often inadequate for the strict application of all the Supplemental Models, it does not put undue emphasis on any one inaccurate number. Second, it does provide an order of magnitude estimate for these fracture costs to society: "the costs are at least [an amount] and may be as high as [an amount]". Finally, this approach allows comparisons between events to be made in a general sense. That is, more costly events may indicate a need for more fracture prevention techniques, or for additional research, etc.

Translation of Findings Between Events

Another technique utilized to make better estimates was the translation of information between events. In simple terms, this meant that findings relating to one class of events and reported from one area of the economy were applied to the same class of events as reported from other areas. For example, the Department of Defense maintains extensive records on all accidents that occur (as well as their causes and consequences) on military bases, including those accidents which occur in base housing and in base communities. By reviewing this rather detailed data base, information on the percentage of accidents due to fracture was obtained. Where applicable, results from on-base, home-related accidents could then be applied to the more general class home-related or other civilian-related events, especially when it was the only reasonable information that could be obtained. Overall, the technique of supplementing information on one event with findings from a different, yet basically similar, type of event allowed estimates to be made that otherwise would have been less accurate, at best, or nonexistent, at worst.

Results

Supplemental Model results for all events are described in Table 15, which details World I results. Since, by definition, no fracture events within scope can occur in World II the results in Table 15 also represent the difference between World I and World II. The maximum/minimum cost ranges for each entry are shown.

Note that the costs are divided into "resource" costs and "imputed" costs. The latter include disability and pain and suffering associated with injuries, the cost of death, and environmental degradation (costs which are not included directly in the Input/Output analysis). Also included in imputed costs are nonrecoverable cargo losses (goods lost in transit as a result of a fracture event), which also appear in the I/O table as a separate column of Final Demand. Resource costs, including medical costs, insurance administration costs, and environmental cleanup costs, are directly included in the I/O model. To avoid double counting, these costs ($228.5-$732.8 million) should not be added to the I/O results. On the other hand, the imputed cost total ($286.8 million to $1,084.9 million) should be added to the World I-World II fracture cost difference reported by I/O model results.

Supplemental Model results for the World I-World III differences were also calculated on an event-by-event basis with the totals presented in Table 16. Here, total imputed costs (to be added to the I/O results) are $27.6 to $122.7 million; resource costs (not to be added) are $25.7-$78.3 million.

It is noted that the fracture-related costs derived from all the events represents a very small, and almost negligible, fraction of those estimated from the I/O analysis. That this should be the case appears reasonable on two counts. First, regardless of how tragic, spectacular, or newsworthy, these events do not occur with great frequency. Second, the Supplemental Models represent sporadic and discontinoous events, while the I/O model defines situations where fracture or the use of resources in their prevention are routine aspects of all production processes and all end uses throughout the entire economy. Thus, while many fracture events create public awareness of fracture problems, they represent only a small portion of the total societal cost of fracture.

TABLE 15. SUPPLEMENTAL MODEL RESULTS FOR WORLD I MINUS WORLD II DIFFERENCES (Million of 1978 Dollars)

	Resource Costs	Imputed Costs
Injuries	$44.7 - 132.8	$223.2 - 570.6
Deaths	0	$63.4 - 454.3
Property	$183.8 - 600.0	$22.2 - 28.2**
Environmental	*	$0.2 - 60.0
Total	$228.5 - 732.8	$309.0 - 1,113.1

Source: Appendix E, Table E-24.

* See Environmental Clean-Up Sector in I/O Model.

** This figure, although included as an imputed cost, has been entered into the Input/Output as a "LOSS" sub-vector of Final Demand.

TABLE 16. SUPPLEMENTAL MODEL RESULTS FOR WORLD I MINUS WORLD III DIFFERENCES (Millions of 1978 Dollars)

	Resource Costs	Imputed Costs
Injuries	$4.5 - 17.0	$22.5 - 65.2
Deaths	0	$5.1 - 51.2
Property	$21.2 - 61.3	$3.40 - 4.10**
Environmental	*	$0.02 - 6.0
Total	$25.7 - 78.3	$31.0 - 126.8

Source: Appendix E, Table E-26.

* See Environmental Clean-Up Sector in I/O Model.

** This figure, although included as an imputed cost, has been entered into the Input/Output as a "LOSS" sub-vector of Final Demand.

It is appropriate to note, at this point, an additional comment relative to both the scope and the objectives of the present study. Estimates by the National Safety Council (see Table E-2) indicate that the cost of automobile-related accidents alone amounted to $34.3 billion in 1978, a value nearly 20 times as great as the maximum of that estimated for all resource and imputed costs in this analysis. Furthermore, NSC's accounts of all accidents (motor vehicle, work, home, public recreation and other transportation) were greater than the maximum Battelle estimate by a factor of nearly 40.

Two significant conclusions may be drawn from these comparisons.

(1) Events which result from fracture within scope, even when considering any errors that might arise from the approximations made in this study, contribute only a small fraction of the costs of all events; and

(2) The reduction in societal costs associated with the vast majority of events can come about only through the efforts of parties other than those concerned directly or indirectly with fracture technology. Specifically, research in this area is most properly under the purview of organizations that are concerned with efforts in the fields of human and institutional factors.

VII. THE IMPACTS OF FUTURE RESEARCH

From the outset of this program, the objectives have been basically two-fold: (1) the estimation of the costs of fracture, and (2) the estimation of the potential impact of research on these fracture costs. As noted in Chapter II, and shown schematically in Figure 2, the present costs of fracture contain two components that suggest the need for further efforts at fracture prevention.

First, there is a component of presently reducible costs (designated as World I-World III) which may be addressed through broader application of known technologies. This potential annual cost reduction, including those calculated from both the Input/Output Model and the Supplemental Models, amount to $25.6 billion--not an unsubstantial target. By the definition of World III, this figure represents the cost savings which could accrue through extensive technology transfer, education, adaptation, and procedural modification. This activity does not require the conduct of additional research on fracture.

However, it must also be emphasized that no estimates have been made of all the costs that would have to be incurred in order to attain World III. At the present stage, no estimates have been made--nor were they to be made under the scope of the present NBS project--of the social investment needed to satisfy the conditions of World III. No figures are available to approximate, e.g., the costs (to society or to the firm) of effecting a broad-scale technology transfer activity, providing and absorbing the necessary information in a usable form.

Second, there is the remaining $60.9 billion difference (exclusive of the nonduplicated costs associated with the fracture-relevant events) which represent the presently nonreducible costs of fracture, that amount which represents a target to be pursued through future research. By the very definition of the Worlds and the differences among them, it follows that the conduct of selected research programs may result in the enhancement of a basic store of knowledge and practice such that the differences between World III and World II may be diminished. Future research, in the context of the schematic diagram of Figure 2, would permit a decrease in the future World III-World II gaps. Dissemination and application of known research results will serve to decrease the World I-World III gaps regardless of how these gaps change with advanced research.

What we have termed "World IV" is the state of the economy which can be attained as a result of undertaking and completing future research in fracture control and prevention. World IV is a world in which future best practices have been determined and achieved. It can almost be conceived as an ultimate best practice world, although, strictly speaking, we cannot know (we can only conjecture) what the ultimate would be.

Before delving into the specifics of the World IV considerations, we must reemphasize that the accomplishments achieved by future research will not come free of charge. Not only will there be an investment required to define World IV, but also there will be that investment required to attain World IV.

Factors for Consideration

In estimating the potential impact of research on future costs of fracture, we consider two avenues of emphasis: (1) the choice of generic research to be pursued, and (2) the selection of the most appropriate sectors for further study.*

The procedure adopted in estimating the impacts of future research consisted of seven steps:

(1) selection of broad categories of research areas, maintaining consistency with the definitions of World II and the scope of the program

(2) identification of major candidate sectors

(3) identification of more specific research needs pertaining to the chosen sectors

(4) aggregation of those needs into subclasses of the broad categories of (1) above

(5) estimation of probabilities of accomplishing research goals and the assignment of weights to individual goals

(6) estimation, by sector, of a weighted reduction factor applicable to targeted dollar-flow differences

(7) extension and application of the technique to all sectors and estimation of the total World III-World IV, Future Reducible Costs.

In many respects, this approach is similar to the data collection process which was employed in characterizing Worlds II and III: high-priority sectors were selected for detailed study; principal features and factors were identified and evaluated; generalizations based upon these factors were developed (the row rules); and these generalizations were applied to the remaining sectors (with appropriate modification, where necessary).

Selection of General Research Areas

With an appreciation of fracture phenomena, the vast number of factors which contribute to fracture, and the efforts which are presently put forth to preclude undesirable fracture, a sampling among research scientists

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* It will be seen later in this Chapter that--just as in the case of the row rules--all sectors eventually can be included in the analysis.

and practitioners could produce a list of potential fracture-prevention research projects that could be pursued. To be sure, the failure of materials and structures can be caused by so many different factors that virtually hundreds of <u>different</u> types of programs could be undertaken to reduce the probability of fracture.

Rather than undertake such a survey, it is more appropriate for this study to define generic research areas and to apply the findings to three sets of sectors: (1) those which represent the largest potentials for cost savings (measured either in terms of social savings or in terms of total output); (2) those which represent, or are closely associated with sectors where failure has severe or highly visible consequences; and (3) all others.* In order to achieve a consistency in approach, the generic definitions of research areas (at two levels of specificity), were established by a reconsideration of the conditions used to define World II. To facilitate the discussion, we repeat (from Chapter II) the eleven basic conditions imposed on World II:

(1) Each material's properties will have no variability.

(2) Each material's mechanical properties will be defined as being four standard deviations above the mean of the distribution which is now achievable. The mechanical properties include the yield and ultimate strengths at the temperature of interest.

(3) We assume no unfavorable influence on any one of a material's mechanical properties as we reduce the variability of its other properties.

(4) A material may be substituted, if, in 1978, the primary reason for its not being used in that same application was its susceptiblity to fracture.

(5) It is assumed that materials do not fracture under any conditions unless design specifications are exceeded.

(6) Design will either be load or stiffness limited.

(7) A safety factor of unity will be applied in any case.

(8) Design is carried out with perfect knowledge.

(9) Inspection for fracture relevance is not necessary.

(10) There will be no residual stresses.

(11) There will be no crack initiation, growth, or fracture, either as a result of processing or of service.

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* The criteria for selecting these classes of sectors will be described below.

Since these were the conditions that defined World II (our no-fracture World), it follows that desirable fracture-related research should be directed toward their attainment.

Inspection of these eleven conditions suggests four broad categories of research:

- Research on Materials
- Research on Production and Fabrication
- Research on Design
- Research on Reliability.

Further refinement within each of these four groups, again considering the conditions defining World II, was undertaken after we had identified the sectors showing the greatest potential for fracture reduction.

Sector Selection

As originally conceived, the impacts of future research were to be estimated for sectors selected (either as rows or as columns) representing the largest targets of opportunity, i.e., those in which World III-World II dollar flow differences were greatest. Inspection of the dollar flow tables (as presented in Appendix H) permits a straightforward identification of the twenty rows and twenty columns that contributed most to the presently nonreducible costs of fracture. We can safely assume that future research with respect to these sectors is most likely to generate future savings related to processes (columns) or to products (rows).

This approach has merit in that each candidate column can be targeted in terms of its potential cost savings, and the inputs to that column can then be evaluated on the basis of their probable contributions to that potential. Similarly, identification by the row allows us to identify those purchasing sectors for which the effects of changes in the row input would be greatest.

An alternate selection process that was considered involved the identification of the largest cells in the World III-World II Dollar Flow difference table. This would have identified specific uses of selected inputs; however, to concentrate on cells instead of sectors in setting research priorities would not serve the broader purpose of this study. Thus, the final criteria for identifying sectors for individual study were: (1) the 20 largest row sectors in terms of World III-World II differences in total output; (2) the 20 largest column sectors in terms of World III-World II Social Savings; and (3) additional sectors chosen either on the basis of their visability or on the basis of their perceived social significance.*

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* In addition to the above selection exercise, we also identified the 400 largest individual cells in the World III-World II difference table. As expected, the vast majority of those cells were already included in the selected rows and columns.

As a result of this process, 51 sectors were selected for initial screening (see Table 17).

Identification of Sector-Specific Research Topics

The senior project staff team, augmented by other Battelle research specialists, considered those research topics deemed to be most promising and pertinent to fracture in each of the highest priority sectors. The initial effort in this subtask was directed toward those sectors which have been selected because of (1) their column contribution and (2) their potential to serve as bases for generalization.

Extensive discussions and examination of the difference tables resulted in the development of two cross-matched sets of judgments. First there are the twenty potentially fruitful research areas listed in Table 18, grouped into four broader categories. Second, there are 33 potential savings objectives specifically applicable to the selected set of sectors. In Table 19, these objectives are distributed among 17 principal sectors and the twenty research areas.

As an example of the utility of information in Table 19, we note that:

- More Reliable Castings (Objective #4), would benefit several aspects of Sectors 7B01, 7.03, and 7X04
- Improved Performance of Fabricated Components (Objective #14), would benefit Sectors 8A05, 10.02, 11.01, and others
- Elimination of Potholes (Objective #28), would benefit Sector 19A04.

Other similar kinds of savings would be expected to result from research in the general areas of Defect Elimination.

One can thus read across the rows of Table 19 and obtain a qualitative indication of the types of benefits or savings to which any one of the twenty principal areas of research might lead. Inspection of this same table from a column perspective identifies the general and specific areas of research which might result in substantial reductions in each Sector's inputs.

Probabilities of Research Benefits

The prediction of future trends, activities, and consequences is hardly an area which is subject to detailed analysis. And in few fields of endeavor is prognostication riskier than in scientific and technological research. The history of science can give guidance only where there are records of trends in development that may be expected to continue into the

TABLE 17. CANDIDATE SECTORS FOR WORLD IV CONSIDERATION

SECTOR	TITLE	CRITERIA FOR SELECTION ROW	COLUMN	VISIBILITY
2.01	Iron and Ferroalloy Mining	X		
2A04	Underground Coal Mining			X
2A05	Crude Petroleum	X		X
2.06	Stone and Clay Mining	X		
3A01	Beverages		X	
3B01	All Other Food and Kindred Products		X	
3X05	Fabrics, Yarns, Threads and Soft Floor Coverings		X	
4.07	Pulp, Paper and Paper Products, Except Containers		X	
5.01	Petroleum Refining and Related Products	X	X	X
5.03	Industrial Organic and Inorganic Chemicals	X	X	X
P.07	Plastics Materials, Resins and Synthetic Rubber	X		
P.13	Tires and Inner Tubes		X	X
6A01	Flat Glass			X
6C01	Automobile and Truck Windshields			X
6B03	Structural Concrete Products and Ready-Mixed Concrete	X		
6D03	Clay and Nonclay Refractories	X		
7A01	Iron and Carbon Steel	X	(X)	
7B01	Alloy Steel	X	(X)	
7.03	Aluminum	X		
7X04	All Other Nonferrous Metals	X	X	
8.01	Metal Cans		X	
8A05	Structural Metal		X	
8C05	All Other Fabricated Structural Products		X	
8.06	Screw Machine Products and Stampings	X	X	
9.02	General Industrial Machinery and Equipment		X	
10.02	Construction Machinery		X	
11.01	Motor Vehicles and Parts	X	X	X
11.02	Aircraft and Parts		X	X
11.03	Ship and Boat Building and Repair			X
16.01	Ordnance and Accessories			X
16A02	Sporting Goods and Toys			X
17.01	Railroads and Related Services	X		X
17.02	Local and Other Highway Passenger Transport			X
17.03	Motor Freight and Warehousing	X		X
17.04	Water Transportation			X
17.05	Air Transport			X
17.06	Pipelines			X
18.02	Electric Power	X		X
18.03	Gas	X		
19.01	Construction, Residences		X	
19.02	Construction, Nonresidential Buildings	X	X	X
19A03	Construction, Railroads			X
19B03	Construction, Pipelines			X
19C03	Construction, Other Public Utility		X	
19A04	Construction, Highways		X	X
19B04	Construction, Bridges			X
19C04	Construction, Dams			X
20.01	Wholesale and Retail Trade	X		
20XB2	Finance, Real Estate and Advertising	X		
20C05	Environmental Cleanup			X
20D05	All Other Business and Professional Services	X		

TABLE 18. RESEARCH LEADING TO POTENTIAL SAVINGS

Intrinsic Materials Research

This area includes research to improve the base-line properties of existing materials and to develop new materials. It includes:

Fatique: increased endurance limits and slower crack growth rates.

Strength: higher yield strengths (or fracture strengths for brittle materials). Also higher strength/weight ratios.

Toughness. higher fracture toughnesses including lower ductile/brittle transition temperatures. Particular attention to higher toughness/strength ratio.

Temperature: higher softening temperature, longer stress-rupture life, and increased resistance to thermal shock.

Environment: reduced sensitivity to environmental cracking of non-metals. (Note that environmental cracking of metals is outside the scope of this study.)

New materials*: new composites, amorphous metals, and other advances.

Production and Fabrication Research

This area includes research to produce more efficient and reliable components. It includes:

Joining: improved strength and reproducibility of welds, adhesive joints and mechanical joints.

Residual Stress: reduced residual stresses in welds, castings, and mechanically-fabricated parts.

Defect Elimination: decreased reject rates due to elimination of strength-limiting defects, improved surface finishing.

Process Control: reduced scatter of fracture-related properties.

Process Development: improved fracture behavior due to advances in casting, deformation processing (including machining), sintering, and composite manufacturing. Also, development of new manufacturing technology.

*See Note, end of Table.

TABLE 18. (Continued)

Design Research: This area includes research to develop lighter and more effective designs. It includes:

> Material Testing: improved accuracy of prediction of structural behavior from laboratory test data.
>
> Energy-Absorbing Design: improved methods of reducing stresses due to impact loads.
>
> Computational Efficiency and Accuracy: less expensive and more reliable stress analysis methods.
>
> Fracture-Prevention Design: more effective design of stiffeners and other crack arrestors. Design of joints with higher efficiency.

Reliability Research: This area includes research into the suitability and service performance of manufactured products. It includes:

> Testing: more efficient testing of structures and parts. Particularly important is improved fatique life prediction.
>
> Inspection: more sensitive detection of flaws and cracks, and detection of local damage accumulation.
>
> Maintenance: prevention of service overloads arising from changes in operating performance.
>
> Repair: improved lifetimes due to better repair of defects.
>
> Protection: longer lifetimes due to better packaging, handling and overload protection. Includes shielding non-metals from aggressive environments and improved thermal shielding.

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*NOTE. The category of "New Materials" does not imply a search for breakthroughs or entirely new concepts. In the context of this analysis, "New Materials" include those basic materials concepts which have already been established and demonstrated, but where specific development programs have yet to be undertaken.

TABLE 19. AREAS OF POTENTIAL SAVINGS DUE TO RESEARCH
(See notes to Table 19 for significance of code numbers in individual cells.)

RESEARCH AREAS	7A01	7B01	7.03	7X04	8A05	10.02	11.01	11.02	11.03	17.05	18.02	19A03	19B03	19C03	19A04	19B04	19C04
Materials Research																	
Fatigue	1	1	1														
Strength		9	11														
Toughness		2	2														
Temperature		10	10	10													
Environment														26	27		
New Materials								10	24		25			26	27		31
Production & Fabrication																	
Joining	3	3	12	13	3	14	14		14		14	8	14	14		14	
Residual Stress	4	4	4	4	14	14	14		14		14	8	14	14		14	
Defect Elimination	5	4	4	4	14	14	14	14	14		14	8	14	14	28	14	32
Process Control	6	6	6	6	14												
Process Development	7	7	7	7	15												
Design Research																	
Material Testing	4	4	4	4	14			14	14		14	8	14	14			
Energy Absorbing Design						16	16	16	16		16						
Computational Efficiency/ Accuracy						17	17	17	17		17					17	
Fracture Prevention Design						18	18	18	18		18	8	18	18		18	18

TABLE 19. (Continued)

RESEARCH AREAS	7A01	7B01	7.03	7X04	8A05	10.02	11.01	11.02	11.03	17.05	18.02	19A03	19B03	19C03	19A04	19B04	19C04
Reliability																	
Testing/Fatigue Life Prediction	5	4	4	4		19	19	19	19		19	8					
Inspection	5	4	4	4	14	20	20	20	20	20	20	8	20	20	20	20	20
Maintenance	8	4	4	4		21	21	21	21	21	21	8	21	21	21	21	21
Repair	8	4	4	4		22	22	22	22	22	23	8	22	22	22	22	22
Protection							23			33	23		23	23	29	30	

Notes to Table 19.

1. Development of fatigue-resistant materials
2. Development of tougher materials
3. Improvements in welding
4. More reliable castings
5. More reliable casting and rails
6. Greater material uniformity
7. Improved casting technology particularly important
8. More reliable rails
9. Development of strong alloys
10. Development of more creep-resistant alloys
11. Higher yield strength/elastic modulus ratios
12. Improved weldability of aluminium
13. General improved weldability
14. Improved performance of fabricated components
15. Developments of continuous castings
16. Better means of limiting loads to design levels
17. More complete and accurate knowledge of local stresses
18. Development of fracture-proof designs
19. Better test methods, particularly for life prediction
20. Improved sensitivity of defect and damage detection
21. Improved maintenance
22. Improved repair
23. Improved air bags, pressure release valves, governors, etc.
24. Materials substitution for ships
25. Materials substitution for electric power generation
26. Improved plastic pipe
27. New and improved paving materials
28. Prevention of potholes
29. Methods of reducing environmentally-caused deterioration of highways
30. Improved methods of limiting overloads
31. New and improved dam materials
32. Elimination of structural defects in dams
33. Improved crashworthiness

future; but forecasts are impossible where major breakthroughs and discoveries have altered historical trends. Experimental and theoretical investigations have advanced the state of the art in discontinuous sequences, disrupting an orderly advance and replacing it with entirely new directions or unexpected frameworks of understanding.*

While the histories of science can document the existence of breakthroughs and the conditions under which they occurred, such accounts offer no means of predicting when or if new breakthroughs will occur. One can only be assured that they may occur. Thus, as we consider the extent to which future research can affect presently nonreducible costs of fracture, we must confine our consideration to what might be expected from the complete success of a systematic approach, given the trends already established. That is to say, the question addressed is: Barring unexpected developments in our basic understanding and application of physical processes, to what extent would continued, advanced research in [a particular field of study] alter presently nonreducible costs of fracture?

We return now to the differences between Worlds II and III. World III is a situation that could be realized if everyone followed currently known (1978) best practices in the avoidance of fracture. World II, on the other hand is a situation in which we have relative levels of perfection without having to work for them. This means that, while successful R&D can move us toward World II, by definition we can never quite achieve it. In no particular instance, however, do we know precisely where that limit is beyond which R&D cannot take us. Nevertheless, we assume that a targeted 100 percent success in research will eliminate a given World III-World II difference--but we know that success will never exceed, say, 90 percent. We make this assumption separately for each of the Sectors and each of the research subareas shown in Table 19.

Referring, for example to the column for Sector 7.03 (Aluminum), we have assumed that the World III-World II difference would disappear if complete success (known impossible) could be achieved in each of the broad categories of research (Materials, Production and Fabrication, Design, Reliability). Moreover, complete success in Design would be accomplished if it were achieved in the single subarea, Material Testing.

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* The popular expression "...taking a quantum jump..." has spread into use by all manner of statesmen, politicians, educators and nontechnologists, with little or none of its original meaning.

To choose another example, in Sector 10.02 (Construction Machinery), Materials research is not a critical category. However, the Sector will be affected by all three of the remaining broad areas*. Similarly, Sector 17.05 (Air Transport) is critically affected only by the broad area of Reliability research.**

We may now examine each of the nonzero cells of Table 19 individually in terms of two related questions:

(1) What is the probability of attaining complete research success with regard to the subarea (row) as applied to the sector (column)?

(2) To what extent would complete success in this cell affect the World III-World II differences if this were the only cell under consideration?

The results of this inquiry are shown in Table 20, which may be interpreted in the following ways: the numbers in this table represent a best judgment on a scale of 1-10. Therefore, it follows that, for example, if Process Control were the only subarea of research required in connection with Sector 8A05, it is estimated that complete solution of the outstanding process control problems of this Sector would result in a 30 percent reduction in the World III/World II difference. Similarly, if Inspection were the only subarea of research, then 80 percent of the difference could be saved. And, finally, if both Process Control and Inspection problems were solved, the reduction in this Sector's World III-World II difference would involve a weighting factor proportional to the relative contributions of the two broad research areas, Production and Fabrication Research and Reliability Research.

To determine the final weighted reductions in World III-World II differences, as applied to the seventeen high priority sectors of Table 20, we must take two steps. First, the total of 100 percent must be divided among the four major areas of research. A detailed statistical analysis of failure modes, assignment of the most critical factors leading to failure, and a mass of expert opinion probably would be required for a completely defensible distribution. Lacking such data, judgmental estimates were made. As a first approximation, the total 100 "points" were divided among Materials, Production

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* We note that Sector 10.02, involves the processes of constructing heavy machinery (see Appendix C), given the materials that are available. Material research is performed by other sectors and only indirectly impacts Sector 10.02.

** Care must be exercised to avoid falling into a common trap by assuming that this sector (17.05, Air Transport) must surely be concerned with, for example, research in Joining or Fracture Prevention Design. While airline and airplane maintenance staff certainly have more than just a passing interest in these subjects, the definition of the sector precludes the direct involvement with these research areas.

TABLE 20. PROBABILITY OF REDUCING WORLD III-WORLD II COSTS, WHERE 10 = 100 PERCENT COST REDUCTION

	7A01	7B01	7.03	7X04	8A05	10.02	11.01	11.02	11.03	17.05	18.02	19A03	19B03	19C03	19A04	19B04	19C04
MATERIALS RESEARCH																	
Environment														6	7		
Fatigue	2	2	2														
Strength		2	4														
Toughness	6	6															
Temperature		4	4	4													
New Materials								4	6		2			5	8		6
PRODUCTION/FABRICATION																	
Joining	6	6	7	6	6	6	5		6		6	6	4	3		6	
Residual Stress	7	7	7	7	6	6	5		7		6	7	4	3		6	
Defect Elimination	6	7	7	7	5	5	5	4	7		5	6	7	7	8	5	4
Process Control	5	8	8	8	3												
Process Development	7	7	7	7	8												
DESIGN RESEARCH																	
Material Testing	3	3	3	3	3			4	5		3	3	4	4			
Energy Absorbing Design						4	5	3	5		1						
Computation Efficiency/ Accuracy						8	8	8	7		5					7	
Fracture Prevention Design						3	2	3	6		4	2	2	2		7	5
RELIABILITY																	
Testing (Fatigue Life Prediction)	2	2	2	2		4	3	2	3		3	4					
Inspection	8	8	8	8	8	8	9	8	8	8	7	8	8	6	6	8	6
Maintenance	6	6	6	6		5	4	3	5	3	4	5	6	6	5	6	6
Repair	6	6	6	6		5	4	4	4	4	4	3	5	5	5	6	5
Protection							1			2	3		2	1	2	4	
TOTAL																	

and Fabrication, Design, and Reliability Research in the proportions of 30, 30, 30, and 10*.

Where any major research area was excluded from consideration in connection with any sector (Sectors 8A05 and 19B04, for example, had no Materials Research; and Sector 19A04 showed no contribution from Design Research), the 100 points are divided among the remaining areas in accordance with the ratios established in the 30/30/30/10 distribution.**

It was then necessary to distribute the points assigned each major generic area among the individual (four to six) subareas. Again, no detailed analyses were available to guide this process, wherefore the available points were distributed evenly among those areas noted to be important for the given sector.

The final distribution of percentage reduction in costs among the twenty research areas and the seventeen primary sectors is shown in Table 21, where the individual cell entries indicate the percentage by which the World III-World II costs of fracture may be reduced, for each column sector, by the successful completion of the cited research. Similar results for the 14 next most important sectors are shown in Table 22.

Translation to All Sectors

The approach detailed above was carried out essentially as a column-specific exercise for the highest priority sectors, as chosen according to criteria stated earlier.

The same level of detail was not pursued with the remaining sectors. Instead, using the same concepts as applied to the row rules described in Chapter IV, all other sectors were divided into groups such that each group could be treated as similar to one or more of those listed in Tables 21 and 22. The total reducible fractions derived in Table 21 and 22 were then applied to these remaining sectors.

Application of the Reduction Fraction

As noted above, the reduction fraction, RF, is a factor which represents an estimate of the extent to which presently known fracture-related technology will advance in the foreseeable future, without consideration given

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* Sensitivity analyses showed that the 30/30/30/10 distribution was not a significant determinant of the eventual weighted averages. A distribution of 30/20/30/20 or 25/25/25/25 gave essentially the same answers. The total projected impact of future research is the crucial factor.

** Thus, for Sector 10.02, the three major areas (Production and Fabrication, Design, and Reliability Research) are weighted (0/43/43/14) respectively, and, Sector 17.05, the weightings are obviously (0/0/0/100).

TABLE 21. PERCENT REDUCTION IN COSTS, BY RESEARCH AREA, FOR HIGHEST PRIORITY SECTORS

	7A01	7B01	7.03	7X04	8A05	10.02	11.01	11.02	11.03	17.05	18.02	19A03	19B03	19C03	19A04	19B04	19C04
MATERIALS RESEARCH																	
Environment														9.0	15.0		
Fatigue	3.0	1.5	2.0														
Strength		1.5	4.0														
Toughness	9.0	4.5															
Temperature		3.0	4.0	12.0													
New Materials								12.0	18.0		6.0			7.5	17.1		18.0
PRODUCTION/FABRICATION																	
Joining	3.6	3.6	4.2	3.6	5.14	8.57	7.14		6.0		6.0	8.57	5.71	3.0		8.57	
Residual Stress	4.2	4.2	4.2	4.2	5.14	8.57	7.14		7.0		6.0	10.0	5.71	3.0		8.57	
Defect Elimination	3.6	4.2	4.2	4.2	4.29	7.14	7.14	12.0	7.0		5.0	8.57	10.0	7.0	34.3	7.14	12.0
Process Control	3.0	4.8	4.8	4.8	2.57												
Process Development	4.2	4.2	4.2	4.2	6.85												
DESIGN RESEARCH																	
Material Testing	9.0	9.0	9.0	9.0	12.86			3.0	3.75		2.25	6.43	8.57	6.0			
Energy Absorbing Design						5.71	5.71	2.25	4.5		0.75						
Computation Efficiency/ Accuracy						11.42	11.42	6.0	5.25		3.75					15.0	
Fracture Prevention Design						4.29	2.86	2.25	4.5		3.00	4.29	4.29	3.0		15.0	15.0
RELIABILITY																	
Testing (Fatique Life Prediction)	0.5	0.5	0.5	0.5		1.48	0.86		0.75		0.6	1.43					
Inspection	2.0	2.0	2.0	2.0	11.43	2.86	2.57		2.0	20.0	1.4	2.86	2.86	1.5	2.14	2.86	2.0
Maintenance	1.5	1.5	1.5	1.5		1.86	1.14		1.25	7.5	0.8	1.79	2.14	1.5	1.79	2.14	2.0
Repair	1.5	1.5	1.5	1.5		1.86	1.14		1.0	10.0	0.8	1.07	1.78	1.25	1.79	2.14	1.67
Protection							0.29			5.0	0.6		0.71	0.25	0.71	1.43	
TOTAL	45.1	46.0	46.1	47.5	48.3	53.8	47.41	37.5	61.0	42.5	37.0	45.1	41.8	43.0	72.8	62.9	50.7

TABLE 22. PERCENT REDUCTION IN COSTS, BY RESEARCH AREA, FOR SECOND HIGHEST PRIORITY SECTORS

	2A04	3X05	4.07	5.01	5.03	P.07	P.13	6A01 6C01	6B01	6B03	9.02	19.01	19.02
MATERIALS RESEARCH													
Environment						1.2							
Fatigue						0.6							
Strength						1.8		12.0		3.0			
Toughness						1.8		9.0					
Temperature						2.4							
New Materials												9.0	9.0
PRODUCTION/FABRICATION													
Joining											8.57	1.5	1.0
Residual Stress								3.0			7.14		1.0
Defect Elimination		5.0	5.0				4.29	3.0			7.14	1.5	2.0
Process Control		5.0	5.0	7.5	7.5	3.0	4.29	2.0	15.0	3.0			
Process Development													
DESIGN RESEARCH													
Material Testing						3.0	1.43			1.5		3.0	3.0
Energy Absorbing Design							2.86				8.57		
Computation Efficiency/ Accuracy													
Fracture Prevention Design	22.5						4.29	3.0		1.5	8.57	1.5	1.5
RELIABILITY													
Testing (Fatique Life Prediction)						1.0	0.36	1.0		1.0	0.71		
Inspection				5.0	5.0	1.0	1.07				1.43		
Maintenance	7.5			2.5	2.5		0.36				0.71	1.0	1.0
Repair				2.5	2.5		0.71				0.71		
Protection	2.5								5.0				
TOTAL	32.5	10.0	10.0	15.0	15.0	15.8	19.7	33.0	20.0	10.0	43.6	17.5	18.5

to breakthroughs. Any application of RF must then be made relative to existing technology, i.e., that technology which is available regardless of whether it is fully employed in all sectors of the economy.

In order to apply RF to the analysis, one must first note the significance of the Social Savings/Cost coefficient in the intermediate input matrices. It has been shown elsewhere in this report that the Social Savings/Cost coefficient in a single sector for, say, World III (expressed herein as S_{III}) represents the fractional dollar's worth of inputs to that sector that could be saved by employing best fracture control practices. Similarly, S_{II} results from having a no-fracture World. Hence, the difference $S_{II}-S_{III}$ is a measure of the fractional dollar's worth of inputs which would accrue in the "transition" from World III to World II, both measured in terms of deviations from World I technologies and practices.

The entire rationale for defining a World IV is to estimate the dollar changes that could result from the conduct of R&D beyond that which characterizes present technologies, with the assumption that these advances would then be translated into practice. The concept of World IV thus translates into that asymptote which is, in reality, a "future World III".

In order to estimate the position of that future World III, (relative to World II and III), we first apply the potential social savings difference for each individual sector $(S_{II}-S_{III})_i$ to the total output of that sector in World III $(TO_{III,i})$, multiply that value by the corresponding reduction fraction, and sum over all sectors. Thus,

$$\text{World III-World IV} = \sum_i (S_{III} - S_{II})_i \; TO_{III,i} \; (RF)_i$$

This approach yields a value of \$18.5 billion (measured in 1978 dollars) which might be saved strictly through the conduct of R&D in a variety of fracture-relevent programs. In addition, the calculation shows that nonreducible future costs sum to \$55.6 billion. The sector detail for these figures is shown in Table 23.

The total figure above (\$55.6 billion) is somewhat smaller than that calculated from the World III-World II difference tables (\$60.9 billion, see Appendix H) and as also shown in Table 24 (following Chapter). That such should be the case is readily understood from the fact that this summation is based on social savings coefficients (resulting from technological change) and does not incorporate any changes in demand.

We wish to reemphasize that these World IV calculations are not the result of the rigorous simulation effort which characterized the other three Worlds. As was stressed in Chapter I, the mere summation of fracture-relevant processes and events would have underestimated the total cost of fracture, because it would not have accounted for the complex interindustry transactions which describe the U.S. economy. For this same reason, the calculations of World IV are, at best, only approximations. However, they involve

TABLE 23. FUTURE REDUCIBLE AND NONREDUCIBLE COSTS, BY COLUMN SECTOR

Sector	S_{II}	S_{III}	ΔS	TO_{III} (Millions)	$\Delta S\ TO_{III}$ (Millions)	Reduction Fraction	Reducible Costs (Millions)	Nonreducible Costs (Millions)
1.01	.01034	.00512	.00522	41235.0	215.3	.150	32.3	183.0
1.02	.00626	.00310	.00316	63686.9	201.3	.150	30.2	171.1
1A03	.00151	.00074	.00077	4455.8	3.4	.150	0.5	2.9
1B03	.00725	.00243	.00482	2851.4	13.7	.150	2.1	11.6
1.04	.00256	.00154	.00102	2420.8	2.5	.150	0.4	2.1
2.01	.01224	.00433	.00791	5350.9	42.3	.200	8.5	33.8
2X02	.01017	.00409	.00608	4061.8	24.7	.200	4.9	19.8
2A04	.02715	-.02858	.05573	8538.8	475.9	.325	154.7	321.2
2B04	.00447	.00215	.00232	14098.7	32.7	.200	6.5	26.2
2C04	.00434	.00205	.00229	288.2	0.7	.200	0.1	.6
2A05	.01060	.00431	.00629	82407.0	518.3	.200	103.7	414.6
2B05	.01345	.00548	.00797	13063.1	104.1	.200	20.8	83.3
2.06	.01243	.00559	.00684	9612.5	65.8	.200	13.2	52.6
2.07	.00846	.00347	.00499	1821.6	9.1	.200	1.8	7.3
3A01	.03644	.00969	.02675	37203.9	995.2	.100	99.5	895.7
3B01	.01274	.00597	.00677	203152.1	1375.3	.100	137.5	1237.8
3.02	.00574	.00003	.00571	14639.0	83.6	.100	8.4	75.2
3X03	.00594	.00010	.00584	11480.2	67.0	.100	6.7	60.3
3X05	.03390	-.00651	.04041	29404.3	1188.2	.100	118.8	1069.4
3A07	.09682	.02478	.07204	492.8	35.5	.100	3.6	31.9
3B07	.01373	.00278	.01095	3658.8	40.1	.100	4.0	36.1
3X08	.00423	.00166	.00257	55526.9	142.7	.100	14.3	128.4
4.01	.01597	.00616	.00981	9588.9	94.1	.100	9.4	84.7
4.02	.02810	.01184	.01626	7649.5	124.4	.100	12.4	112.0
4.03	.01014	.00365	.00649	19794.4	128.5	.100	12.8	115.7
4.04	.05001	.02115	.02886	877.0	25.3	.100	2.5	22.8
4XA5	.03115	.01343	.01772	15531.5	275.2	.100	27.5	247.7
4XB5	.03164	.01276	.01888	6316.3	119.3	.100	11.9	107.4
4.07	.01864	.00833	.01031	67737.9	698.4	.100	69.8	628.6
4.08	.01379	.00398	.00981	13027.4	127.8	.100	12.8	115.0
5.01	.01475	.00671	.00804	127050.8	1021.5	.150	153.2	868.3
5.02	.01535	.00671	.00864	2865.2	24.8	.150	3.7	21.1
5.03	.03064	.01176	.01888	43959.1	829.9	.150	124.5	705.4
5X04	.01502	.00421	.01081	5333.6	57.7	.150	8.6	49.1
5A06	.04652	.01686	.02966	2580.0	76.5	.150	11.5	65.0
5B06	.01427	.00537	.00890	4684.5	41.7	.150	6.3	35.4
5.09	.01188	.00407	.00781	12830.9	100.2	.150	15.0	85.2
5X10	.01310	.00502	.00808	16572.0	133.9	.150	20.1	113.8
5.12	.02570	.01134	.01436	5310.1	76.3	.150	11.4	64.9
P.07	.00581	.00097	.00484	15501.1	75.0	.158	11.9	63.1
P.08	.01913	.00163	.01750	5958.4	104.3	.180	18.8	85.5
P.13	.17021	.00402	.16619	10658.5	1771.3	.197	349.0	1422.3
PA14	.02963	.00525	.02438	2992.8	73.0	.180	13.1	59.9
PB14	.02830	.00736	.02094	4925.0	103.1	.180	18.6	84.5
PA15	.16235	.02362	.13873	3512.8	487.3	.180	87.7	399.6

TABLE 23. (Continued)

Sector	S_{II}	S_{III}	ΔS	TO_{III} (Millions)	$\Delta S\ TO_{III}$ (Millions)	Reduction Fraction	Reducible Costs (Millions)	Nonreducible Costs (Millions)
PB15	.07078	.02416	.04662	3669.3	171.1	.180	30.8	140.3
PC15	.03292	.01133	.02159	13288.6	286.9	.180	51.6	235.3
6A01	.10471	-.00403	.10874	1585.1	172.4	.330	56.9	115.5
6B01	.09818	.01106	.08712	5124.0	449.5	.200	89.9	359.6
6C01	.05065	.00445	.04620	712.0	32.9	.330	10.9	22.0
6D01	.05730	.00947	.04783	3134.7	149.9	.250	37.5	112.4
6.02	.01332	.00493	.00839	4620.1	39.0	.200	7.8	31.0
6A03	.05117	.00997	.04120	5953.6	245.3	.200	49.1	196.2
6B03	.05652	.01451	.04120	15736.4	661.1	.200	132.2	528.9
6003	.13726	.07554	.06172	3709.1	228.9	.200	45.8	183.1
6A04	.01848	.00513	.01335	4030.9	53.8	.200	10.8	43.0
6B03	.05652	.01451	.04201	15736.4	661.1	.100	66.1	595.0
6B04	.01525	.00573	.00952	3539.9	37.5	.200	7.5	30.0
7A01	.01949	.02252	-.00303	54209.1	-164.3	.451	-74.1	-90.2
7B01	.02800	.01877	.00923	2769.1	25.6	.460	11.8	13.8
7C01	.01742	.01046	.00696	2274.6	15.8	.461	7.3	8.5
7.03	.03847	.01776	.02071	11809.5	244.6	.461	112.7	131.9
7X04	.12212	.04879	.07333	19875.5	1457.5	.475	692.3	765.2
8.01	.18581	.06956	.11625	5636.9	655.3	.450	294.9	360.4
8.02	.20057	.07160	.12897	1128.9	145.6	.450	65.5	80.1
8.03	.02141	.00346	.01795	1541.0	27.7	.450	12.4	15.3
8.04	.02657	.00556	.02101	3927.2	82.5	.450	37.1	45.4
8A05	.17093	.06360	.10733	10784.1	1157.5	.483	559.1	598.4
8B05	.08699	.03233	.05466	4077.8	222.9	.450	100.3	122.6
8C05	.12606	.04707	.07899	17897.2	1413.7	.450	636.2	777.5
8.06	.12938	.05047	.07891	14311.7	1129.3	.450	508.2	621.1
8.07	.01414	.00319	.01095	24909.4	272.8	.450	122.7	150.1
9.01	.06313	.02542	.03771	12002.0	452.6	.450	203.7	248.9
9.02	.08003	.03032	.04971	18964.6	942.7	.436	411.0	531.7
9.03	.05026	.01846	.03180	6113.1	194.4	.450	87.5	106.9
10.01	.07302	.02782	.04520	5690.5	257.2	.500	128.6	128.6
10.02	.07576	.02785	.04791	13677.3	655.3	.538	352.5	302.8
10.03	.06027	.02187	.03840	1829.4	70.2	.500	35.1	35.1
10.04	.06628	.02423	.04205	1195.9	50.3	.500	25.1	25.1
10.05	.06389	.02333	.04056	7580.4	307.5	.500	153.7	153.7
10.06	.06041	.02202	.03839	3000.8	115.2	.500	57.6	57.6
10.07	.03244	.01152	.02092	15845.4	331.5	.500	165.7	165.7
10.08	.05104	.01842	.03262	14874.2	484.3	.500	242.2	242.2
11.01	.06507	.01871	.04636	143366.9	6646.5	.474	3150.4	3496.1
11.02	.14876	.00080	.14796	33866.1	5010.8	.375	1879.1	3131.7
11.03	.05213	.00913	.04300	8407.2	361.5	.610	220.5	141.0
11.04	.10544	.03956	.06588	3637.0	239.6	.400	95.8	143.8
11.05	.04717	.01729	.02988	9133.2	272.9	.400	109.2	163.7
12.01	.00594	.00232	.00362	5144.5	18.6	.450	8.4	10.2
12A02	.04827	.01479	.03348	357.5	12.0	.450	5.4	6.6

TABLE 23. (Continued)

Sector	S_{II}	S_{III}	ΔS	TO_{III} (Millions)	$\Delta S\ TO_{III}$ (Millions)	Reduction Fraction	Reducible Costs (Millions)	Nonreducible Costs (Millions)
12B02	.05612	.01920	.03692	5941.6	219.4	.450	98.7	120.7
12.03	.00833	.00086	.00747	12008.3	89.7	.450	40.4	49.3
12.04	.02901	.01176	.01725	3012.6	52.0	.350	18.2	33.8
12.05	.04309	.01574	.02735	8719.8	238.5	.350	83.5	155.0
12.06	.01807	.00802	.01005	10505.8	105.6	.350	37.0	68.6
12A07	.01123	.00329	.00794	841.2	6.7	.350	2.3	4.4
12B07	.02552	.00914	.01638	8017.2	131.3	.350	46.0	85.3
13.01	.04926	.01687	.03239	12474.0	404.0	.450	181.8	222.2
13.02	.04675	.01626	.03049	11099.8	338.4	.450	152.3	186.1
13.03	.00927	.00169	.00758	31720.3	240.4	.450	108.2	132.2
14A01	.04339	-.00087	.04426	584.1	25.9	.450	11.6	14.3
14B01	.05296	.01779	.03517	10369.1	364.7	.450	164.1	200.6
14.02	.04628	.01422	.03206	2968.5	95.2	.450	42.8	52.4
14.03	.01413	.00414	.00999	2253.8	22.5	.450	10.1	12.4
14.04	.02104	.00916	.01188	2677.5	31.8	.450	14.3	17.5
14.05	.02159	.00603	.01556	6202.4	96.5	.450	43.4	53.1
15.01	.00910	.00366	.00544	18015.4	99.2	.450	44.6	54.6
15.02	.01890	.00724	.01166	4913.5	57.3	.450	25.8	31.5
15.03	.00282	.00129	.00153	9449.8	14.5	.450	6.5	8.0
16.01	.03048	.00897	.02151	12665.0	272.4	.400	109.0	163.4
16A02	.02841	.01055	.01786	9834.8	175.6	.400	70.3	105.3
16B02	.01224	.00391	.00833	16364.8	136.3	.400	54.5	81.8
17.01	.01682	.02231	.01451	26794.3	388.8	.400	155.5	233.3
17.02	.02324	.00884	.02093	14266.1	298.6	.400	119.4	179.2
17.03	.01356	.00480	.00876	38898.0	340.7	.400	136.3	204.4
17.04	.02284	.00727	.01557	14250.4	221.9	.400	88.8	133.1
17.05	.03341	.00353	.02988	19486.7	582.3	.425	247.5	334.8
17.06	.01139	.00416	.00723	2428.0	17.6	.400	7.0	10.6
17.07	.00517	.00004	.00513	2005.4	10.3	.400	4.1	6.2
18.01	.00258	.00098	.00160	47348.4	75.8	.350	26.5	49.3
18.02	.00392	.00142	.00250	61323.6	153.3	.370	56.7	96.6
18.03	.00102	.00042	.00060	67670.6	40.6	.350	14.2	26.4
18.04	.00266	.00022	.00244	13800.5	33.7	.350	11.8	21.9
19.01	.03512	.00200	.03312	129921.0	4303.0	.175	753.0	3550.0
19.02	.02516	.00118	.02398	114015.2	2734.1	.185	505.8	2228.3
19A03	.08547	.02691	.05856	3958.7	231.8	.451	104.6	127.2
19A04	.02936	-.00909	.03845	17901.5	688.3	.728	501.1	187.2
19B03	.19509	.06721	.12788	463.4	59.3	.418	24.8	34.5
19B04	.02924	.00810	.02114	5815.4	122.9	.629	77.3	45.6
19C03	.04840	.01378	.03462	37296.4	1291.2	.430	555.2	736.0
19C04	.00870	.00232	.01102	3284.3	36.2	.507	18.3	17.9
19D04	.02177	.00772	.01405	13347.1	187.5	.600	112.5	75.0
20.01	.00051	.00021	.00030	396963.0	119.1	.400	47.6	71.5
20XA2	.00004	.00002	.00002	55997.0	1.1	.400	0.4	0.7
20XB2	.00037	-.00010	.00047	394021.9	185.2	.400	74.1	111.1

TABLE 23. (Continued)

Sector	S_{II}	S_{III}	ΔS	TO_{III} (Millions)	$\Delta S\ TO_{III}$ (Millions)	Reduction Fraction	Reducible Costs (Millions)	Nonreducible Costs (Millions)
20A05	1.00000	.00056	.99944	1006.0	1005.4	.400	402.2	603.2
20B05	.00436	.00161	.00275	46138.0	126.9	.400	50.8	76.1
20C05	.00124	.00041	.00083	1059.2	0.9	.400	0.4	0.5
20D05	.00128	.00062	.00066	80662.9	53.2	.400	21.3	31.9
20.06	.00015	.00007	.00008	27432.5	2.2	.400	.9	1.3
21.01	.00729	.00359	.00370	34008.7	125.8	.400	50.3	75.5
21.02	.00191	.00092	.00099	20.1	0.0	.400	0.0	0.0
21.03	.00219	.00081	.00138	13223.2	18.2	.400	7.3	10.9
21A04	.00040	.00017	.00023	16637.7	3.8	.400	1.5	2.3
21B04	.00066	.00025	.00041	10289.0	4.2	.400	1.7	2.5
21.05	.01237	.00615	.00622	46045.2	286.4	.400	114.6	171.8
21.06	.00095	.00030	.00065	24498.0	15.9	.400	6.4	9.5
21.07	.00069	.00029	.00040	69963.8	28.0	.400	11.2	16.8
21.08	.00046	.00001	.00045	112586.2	50.7	.400	20.3	30.4
22.01	.00153	.00062	.00091	17126.8	15.6	.400	6.2	9.4
TOTALS					55583.8		18502.8	37081.1

sufficiently detailed analyses of the economy to provide guidance concerning the impacts of future research.

Final Comments

During the investigations that identified the principal candidate research areas, a wide range of topics was covered by the Battelle senior team. The results of these discussions have taken into account both the research areas and the materials or processes to which such research would be directed.

The analyses and calculations shown earlier (see Table 21 and 22) indicate, as would be expected, that no single research area will "cure" the problems of fracture; there are many different and important problems which must be solved before significant resource savings can be achieved. There are, to be sure, many fields which have an obvious, direct relationship to fracture phenomena, not the least of which include research on improved materials, more reliable and reproducible processes, and higher resolution flaw-detection devices. In addition, there are those research areas from which advances in understanding or technique--while not pursued specifically for fracture prevention--can have major supporting roles. Among them we include, as examples: research on improved sensors and feedback devices to aid in process control; new equipment for chemical and metallurgical analysis; and nondestructive evaluation devices, indicators and instrumentation. These and other ancillary research areas can be readily identified. However, it was neither possible nor within the purview of this program to trace their potential impact on the future reducible cost of fracture.

VIII. ANALYSES OF RESULTS

In this chapter we intend to examine some of the results of this study, primarily as they are embodied in the several difference tables. This will serve two purposes: first, it will provide some general findings as to the costs of fracture in the total economy and in some of the more important sectors; and, second, it will provide some guidance with respect to uses that can be made of these data and results.

Aggregate Fracture Costs

Taken together, the I/O and Supplemental Models provide an unduplicated cost of fracture of $87.6 billion in full employment 1978. Table 24 shows the details of this estimate. This total is made up of both resource costs (98.7 percent), estimated by the I/O model, and imputed costs (pain, suffering, etc.), estimated by the Supplemental Models. Viewed in other terms, this total can be said to be 29.4 percent presently reducible (by the adoption of best practices), with the remainder (70.6 percent) presently nonreducible.

In regard to the resource costs alone, we find that 83.6 percent are generated in the intermediate economy (i.e., are generally technological in nature) and 16.4 percent involve final demands. This contrasts sharply with the Corrosion Study, in which 29.7 percent of total costs were intermediate, and 70.3 percent involved final demands. There is a further difference between these two studies that should be noted. In the Corrosion Study, Personal Consumption Expenditures (PCE) was almost equal to Private Fixed Capital Formation (PFCF, or private investment). In the Fracture Study, PFCF is more than twice as large as PCE. Technological, rather than demand factors clearly dominate the costs of fracture, while the opposite was true for costs of corrosion.

Costs in Sectoral Terms

When the total costs of fracture are examined in sectoral terms, there are several problems that intrude. One obvious problem is posed by the fact that a sector may be very important in its contribution to, say, total cost, but much less so in its contribution to presently reducible cost. Still another problem derives from the fact that row costs and column costs of a given sector are not necessarily related to each other. For instance, a particular material may be relatively unimportant in its contribution as a column to total fracture costs; but as a row it may impose costs (or permit savings) throughout the economy. A third type of problem involves the basic power of the I/O table, namely, that it accounts for both direct and indirect cost/saving elements. For example, a small technological change in a sector's

TABLE 24. MAJOR COMPONENTS OF FRACTURE COSTS, 1978

	Millions of Dollars		
	Total Costs of Fracture	Presently Reducible Costs	Presently Nonreducible Costs
Total Costs of Fracture	87,627.5	25,759.3	61,868.1
Imputed Costs of Events	1,113.1	126.8	986.3
Resource Costs	86,514.4	25.632.5	60,881.8
Total Intermediate	72,282.8	21,075.8	51,207.0
Total Final Demand	14,231.6	4,556.7	9,674.8
Pers. Cons. Exp.	3,539.4	1,460.3	2,079.2
Priv. Fixed Cap.	8,421.0	2,935.2	5,485.8
Exports	---	---	---
Federal-Military	1,036.6	294.7	742.0
Federal-Civilian	315.8	-69.1	384.9
State & Local	890.9	-68.0	959.0
Net Invent. Ch.	---	---	---
Cargo Losses	27.8	3.8	24.0

Source: Difference Tables, Appendix H.

Note: Details may not add because of rounding.

column may relate to large dollar savings simply because of the heavy demand for this sector's products (across the row).*

Sectoral Analysis of Total Fracture Costs

The total costs of fracture (World I-World II) are single counted when examined in column terms (Social Savings), but are multi-counted when examined by the row (Total Output). In Table 25 we contrast these two perspectives in terms of the ten largest sectors as chosen by each criterion.

The 10 highest ranking sectors in terms of World I-World II differences in Social Saving are the sectors most affected by changes in their own technologies. The 10 highest ranking sectors in terms of World I-World II differences in Total Output are the sectors most affected by demand (i.e., by changes in the technologies of other sectors into which they enter as inputs). The first group generally consists of processing or fabricating sectors, the second of material or component sectors. There are four sectors common to both groups (Motor Vehicles, Nonresidential Construction, Other Nonferrous Metals, and Petroleum Refining). Regardless of anything else, these four are large sectors by any criteria.

On the average, at about the 150-order level of detail, Total Outputs are double-counted. Thus, it is not surprising to see that the summed Total Outputs of the second group are approximately twice as large as the summed Social Savings of the first. Taken all together, the sum of all World I-World II differences in Total Outputs is $127 billion, 1.47 times the single-counted Social Savings shown in Table 24.

If we examine this selection of sectors, which probably is reasonably representative, it may provide us with some insights into the relationships between technology and demand (i.e., between column aspects and row aspects) as determinants of fracture cost. First, however, to establish the setting, just how representative are these sectors?

Taken as a group, these 16 sectors have a total social saving difference of $36.3 billion. This is 42 percent of the total Social Saving difference shown in Table 24. Viewed in terms of total outputs, these same sectors account for $68.3 billion, 54 percent of the $127 billion in the difference table. Regardless of how we measure it, these sectors account for a substantial part of total costs of fracture.

Table 26 shows, for each of these 16 sectors, the ratio of the Total Output difference to the Social Savings difference. As this ratio rises above the 16-sector average ($68.3 \div 36.3 = 1.88$), the sector may be viewed as demand driven with respect to its contribution to fracture cost. As this ratio falls below 1.88, the sector may be viewed as technology driven. By this criterion, Sector 18.03 (Gas) is the most demand driven of these sectors. It will be

* The sectoral costs discussed herein are those directly measured by the models. A further analysis, involving normalized data, is shown in the Addendum to this Chapter, which follows directly in the text.

TABLE 25. TEN LARGEST SECTORS BY COLUMN AND ROW MAGNITUDES, IN TERMS OF TOTAL COSTS OF FRACTURE

All Amounts in Millions of Dollars

World I - World II Ranked in Terms of Social Savings				World I - World II Ranked in Terms of Total Output			
	Sector	Social Savings	Total Output		Sector	Total Output	Social Savings
*11.01	Motor Vehicles and Parts	9,211.4	3,249.7	7A01	Iron, Carbon Steel and Coke	27,600.8	728.5
11.02	Aircraft and Parts	4,940.7	1,037.8	*7X04	All Other Nonferrous Metals	7,211.4	1,863.2
19.01	Construction, Residences	4,556.6	107.0	7.03	Aluminum	6,258.0	304.8
*19.02	Construction, Nonresidential Buildings	2,808.6	3,502.5	*5.01	Petroleum Refining and Related Products	4,207.1	1,829.4
3B01	All Other Food and Kindred Products	2,583.4	755.5	18.03	Gas	3,799.6	66.2
				17.03	Motor Freight and Warehousing	3,545.9	492.7
8C05	All Other Fabricated Structural Products	2,205.9	543.6	*19.02	Construction, Nonresidential Buildings	3,502.5	2,808.6
*7X04	All Other Nonferrous Metals	1,863.2	7,211.4				
				*11.01	Motor Vehicles and Parts	3,249.7	9,211.4
*5.01	Petroleum Refining and Related Products	1,829.4	4,207.1	2A05	Crude Petroleum	3,130.0	850.7
8A05	Structural Metal	1,815.0	240.9	20.01	Wholesale and Retail Trade	2,975.3	203.3
P.13	Tires and Inner Tubes	1,792.0	194.3				
	TOTAL	33,606.2	21,049.8		TOTAL	65,480.3	18,358.8

*Sectors which appear in both arrays.

TABLE 26. SELECTED SECTORS IN TERMS OF THEIR RATIO OF TOTAL OUTPUT DIFFERENCE TO SOCIAL SAVING DIFFERENCE, WORLD I-WORLD II

	Sector	Ratio	Taken from Array
2A05	Crude Petroleum	3.68	TO
3B01	Other Fd. & Kind. Prod.	0.29	SS
5.01	Petroleum Refining	2.30	SS, TO
P.13	Tires & Intertubes	0.11	SS
7A01	Iron, Carbon St. & Coke	37.89	TO
7.03	Primary Aluminium	20.53	TO
7X04	Other Nonfer. Metals	3.87	SS, TO
8A05	Structural Metal	0.13	SS,
8C05	Other Fabr. Struc. Prod.	0.25	SS
11.01	Motor Vehicles & Parts	0.35	SS, TO
11.02	Aircraft & Parts	0.21	SS
17.03	Motor Frt. & Warehsg.	7.20	TO
18.03	Gas	57.40	TO
19.01	Nonfarm Res. Construction	0.023	SS
19.02	Nonres. Cosntruction	1.25	SS, TO
20.01	Trade	14.64	TO

Source: Calculated from Table VIII.2:

$$\text{Ratio} = \frac{\text{Total Output}}{\text{Social Saving}}$$

Note: SS = Social Saving difference
TO = Total Output difference

recalled from Chapter IV that several sectors used gas for annealing, unnecessary in World II, and that it entered into a wide range of material related processes. Thus, technological changes in other sectors both directly and indirectly reduced the demand for gas. In contrast, Sector 19.01 (Construction, Residences) is the most technology driven of these 16 sectors. The demand for housing, primarily for family use, is almost totally nonresponsive to fracture considerations; but all the material sectors enter as intermediate inputs, so that it directly achieves a considerable Social Saving.

Sectoral Analysis of Presently Nonreducible Costs

The use of the ratio TO/SS as an analytical tool promises help for subsequent analyses based on the results of this study. This is especially true with respect to the World III-World II differences, where the ratio can help pinpoint the kinds of R&D that promise most benefit for particular sectors. To illustrate this approach, we turn to the World III-World II difference table (shown in Appendix H) and find that the two largest sector differences, using the Social Saving criterion, are:

Sector	SS Difference	TO Difference
11.01 Motor Vehicles	$6,529.2 Million	$1,813.1 Million
11.02 Aircraft	4,913.6 Million	654.4 Million

Using the Total Output criterion, the two largest sectors are:

7A01 Iron, Carbon Steel*	$-492.2 Million	$16,840.3 Million
7X04 Other Nonfer. Metals	893.4 Million	4,618.2 Million

These four sectors can be expected to behave in the same general manner discussed above, making a repetition of that analysis unnecessary. Suppose, however, we take three other sectors, all related to rail transport, and examine them with this same approach:

Sector	SS Difference	TO Difference	TO/SS
11.04 Locomotives, Railcars, and Rapid Transit Cars	$216.0 Million	$ 224.3 Million	1.04

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* Note the anomaly, to which attention has already been called, affecting this sector. Nevertheless, if we ignore the minus sign of the SS entry, the TO/SS ratio would be in the range expected for this sector in terms of the World I-World II discussion, above.

17.01 Railroads and Related Services	\$356.7 Million	\$1,904.7 Million	5.34
19A03 Construction, Railroad	\$206.1 Million	\$ 300.3 Million	1.46

Note that presently nonreducible costs are particularly demand driven for only one of these three sectors (17.01), while the other two are much more technology driven. It will be recalled from earlier discussions that the demand for rail transport is affected by indirect factors, such as the weight reductions which follow from the materials rules. Therefore, the kinds of R&D that are most likely to reduce the future fracture costs of this sector would be those permitting further shifts toward weight reductions throughout the economy, not those directly affecting the railroads. For the other two sectors (11.04 and 19A03), both of which are technologically sensitive, active (direct) rather than passive (indirect) reductions in future fracture costs are possible. R&D directed toward materials characteristics, manufacturing processes and construction methods, would all have the potential for benefits.

Fracture Costs at the Cell Level

At many points in earlier discussions, particularly those related to sector selections for World IV examination, the role of the individual cell has been downplayed somewhat. This treatment of the cell had best be put into a proper perspective. In making all the between-worlds adjustments, the cell has been the focus of activity: it is important, and nothing can reduce that importance. Nevertheless, as an element of these analyses, the cell tends to receive lower emphasis than either the row or the column, and rightly so: it is difficult to generalize from a cell.

Still, the cell enters into these analyses, and some attention should be given it at this point. A few illustrative cases, chosen somewhat randomly will suffice.

Largest Cells. In an earlier discussion, it was pointed out that positive entries occur in the World III-World II difference table when the World III value exceeds the World II value, and therefore indicates an opportunity for future reductions in fracture costs. Among the very largest cells in this table are several which involve Sector 7A01 (Iron and Carbon Steel) either as a row or as a column.

The entry 2.01/7A01 (that is, iron ores into iron and steel) is \$1.4 billion. Since this is an input of an essential raw material, it is a truly technical requirement; but it cannot be significantly altered except by changing the demand for iron and steel. In other words, the potential future reductions in this use of resources will result from R&D affecting the use of metal, not its production. Still another large cell in this 7A01 column is the 7A01 diagonal, \$2.1 billion. In the metals industries, the diagonal generally involves the use of scrap in the production of metal (i.e., recycling). Obviously, recycling is socially desirable. It can be affected from the technical side by altering or choosing primary/secondary metal processes. Since, from the technological point of view, the only choice for reducing the diagonal is to use more ore, we do not want to reduce this diagonal coefficient. Therefore, the only way we can achieve desirable future reductions in this fracture cost would again be by R&D affecting the use of metal.

Iron/steel as a row enters into several large cells, always as an important material for processing by the column sector. Four such cells are 7A01/8A05 (iron and steel into Structural Metal), $778 million; 7A01/8C05 (into All Other Fabricated Structural Products), $923 Million; 7A01/8.06 (into Screw Machine Products and Stampings), $903 million; and 7A01/11.01 (into Motor Vehicles and Parts), $4.4 billion. All these cells involve the direct fabrication of iron and steel; and future reductions in them can be made by R&D which either directly reduces the inputs of the metal into the products, or indirectly reduces the demand for the products. In terms of fracture-relevance, only the former offers promise of significant reductions. These future reductions may be achieved, however, by either of two main paths: (a) improving the characteristics of the metal, so that less can be used in almost any product; or (b) changing the design, processing, or use of the products so that they can function safely with less metal.

There is still a third path to future reductions in these material-related costs of fracture which should be discussed, but about which little specific can be said. This involves the substitution of advanced polymers (from P.07) or ceramics (from various sectors in Group 6) for iron and steel. The difficulty with this path is that the requisite R&D must take place in connection with other materials and must achieve both fracture-relevant and economic substitutability. This last condition will be very hard to meet for a variety of reasons. First, R&D with respect to iron and steel has already been highly successful, and many improvements exist that have not yet been fully exploited. Second, it will be hard for other materials to match all the other, nonfracture characteristics of iron and steel which make these latter such dominant materials. Third, both productive technologies and capital equipment must be changed as part of the material substitution, and these can be quite costly. And fourth, producers are accustomed to iron and steel. They think in those terms, are familiar with those suppliers, and may look with suspicion on proposed substitutes.

Anomalous Cells. A negative cell in the intermediate matrix of the World III-World II dollar difference table reflects an anomaly in that the level of purchase in World II (the base World) is larger than it is in World III (the best fracture-control practice world). There are three such anomalies in this table: P.07/P.13 and PB14 (Plastics Materials, Resins and Synthetic Rubber into Tires and Inner Tubes, and into All Other Rubber Products), and 7A01/11.02 (Iron and Carbon Steel into Aircraft and Parts). The first two derive from the fact that in the best practice World, natural rubber will replace synthetic rubber, while in the no-fracture World there is no difference in their fracture characteristics and synthetic rubber will be used (as it is in World I). The third derives from the fact that, in the no-fracture World, carbon steel will have fracture strength that allows it to be substituted for alloy steels and exotic metals. The presence of these anomalies tells us nothing useful about the desirable paths to World IV.

Future Costs of Fracture

In Table 24, above, we summarized the statistical findings of the I/O model with respect to costs of fracture. At this point, we need to add to these findings those from Chapter VII concerning the future. Given all the assumptions necessary for the estimation of World IV conditions, we have been able to estimate one part of the future, namely the future reducible costs measured on the Social Savings row across the intermediate matrix. This cost element, $17.0 billion, is shown in the fourth column of Table 27. With this value and a few simple assumptions it becomes possible to summarize the elements thought to affect fracture costs.

Future Reducible Costs

The average ratio of Final Demand to Intermediate resource costs in the three cost elements from the I/O model is 0.203. If we assume that this relationship holds for future reducible costs, Final Demand changes would add $3.5 billion and total Resource Costs would be $20.5 billion. In the three modeled elements, the ratios of Imputed to Resource costs average to 0.0113. If we assume that this ratio holds for future reducible costs, Imputed Costs would be $231.7 million, and All Costs would be $20.7 billion. By definition, future nonreducible costs would be the remainders after subtracting future reducible from presently nonreducible costs.

The Issue of Reliability/Sensitivity

The evaluation of the findings of the "Cost of Fracture" study requires an assignment of confidence intervals to the results. In order to address this issue, it is first necessary to consider a fundamental difference between the measurement of physical science parameters and those of the non-physical sciences. Measurements in this latter category (including the social sciences) are far more methodologically complex and may also be subject to influences that preclude direct comparison with the physical sciences. Examined below are some of the elements that cast doubt on this analogy; also indicated are the procedures that will be followed in evaluating the present study.

TABLE 27. SUMMARY OF ELEMENTS IN THE COST OF FRACTURE

		Millions of Dollars			
		Presently		Future	
Kind of Cost	Total Cost(1)	Reducible Cost(2)	Nonreducible Cost(3)	Reducible Cost(4)	Nonreducible Cost(5)
All Costs	87,627.5	25,759.3	61,868.1	20,737.8	41,130.3
Imputed Costs	1,113.1	126.8	968.3	231.7	736.6
Resource Costs	86,514.4	25,632.5	60,881.8	20,506.1	40,375.7
Intermediate	72,282.8	21,075.8	51,207.0	17,045.8	34,161.2
Final Demand	14,231.6	4,556.7	9,674.8	3,460.3	6,214.5

Source: Tables 23 and 24.

Notes:

(1)Total Cost = World I-World II.

(2)Presently Reducible Cost = World I-World III.

(3)Presently Nonreducible Cost = World III-World II.

(4)Future Reducible Cost: Intermediate costs generated from World IV
Final Demand = 0.203 x Intermediate
Resource = Intermediate + Final Demand
Imputed = 0.0113 x Resource
All Costs = Resource + Imputed

(5)Future Nonreducible Cost (on each line) = Presently Nonreducible Costs - Future Reducible Cost.

The Observed/Observer Problem

It has been said that asking a person to examine and draw inferences from socioeconomic situations is like asking a hydrogen atom to write a chemistry book. In dealing with the world of nature, the scientist is removed to the degree that objectivity is relatively easy to achieve; in dealing with social phenomena, the scientist is immersed in and is a part of his data base. Moreover, in the natural world, the basic unit of reaction (the atom or molecule) is so small that even the smallest sample is subject to the statistical "law of large numbers". In the social world, the basic unit of reaction (the person, family or firm) is no smaller than the scientist--and often may be larger--and samples of one are often all that are available.

The Indeterminacy Principle

Heisenberg's principle that the act of observation alters the thing being observed is far more fundamental to the social sciences than to the natural sciences. When we construct a model in the social sciences, we must operate with observations that are essentially cross-sectional snapshots of a smooth flow. Moreover, unlike the world of short-term physical phenomena in which universal constants (parameters) exist, there are no parameters in the social sciences--only variables that change more slowly than other variables.

The I/O model, probably the most complete description of a total economy that has ever been devised, is obviously only an approximation of the real world. First, it is linear; reality may well be curvilinear. Second, it is highly aggregated in its statement of interindustry flows; reality is many orders of magnitude more disaggregated. Third, it is static; reality is dynamic. Despite all this, the I/O model does provide results that are descriptive of reality. The question is, <u>to what degree</u>? In all likelihood, this question can never be answered fully for the following reasons:

- The above-mentioned observed/observer relationship.
- The fact that human (and therefore social and economic) history is open-ended to the extent that the past is never precisely repeated. That is to say, we never have an opportunity to measure anything twice.

The Problem of Aggregation

When we attempt to quantify economic relationships, especially relationships involving levels of or changes in technology, we are faced with the fact of aggregation. Regardless of how finely we define a product or group of products, there are always two or more alternative processes by which it can be produced. In the real world this means that, for any feasible level of sectorization, there are probably several different processes by which a sector's output is being produced--older processes which are not yet discarded and newer ones which are just diffusing into general use.

Different technologies imply different coefficients. Thus, at any point in time, the coefficients for any given sector are, by definition, the weighted averages of the coefficients that would describe the several separate technologies. To the extent that production decisions affect them differentially, these separate technologies will have weights that vary continuously (and perhaps even erratically) over time. For example, if demand for a product falls off and/or if its market price declines, manufacturers will tend to shift production away from currently more costly processes to those that are less costly. Therefore the coefficients for that sector will vary with the degree and nature of capacity utilization, even though no new capacity is created or old capacity retired.

The consequences of this are that different data sources may differ--extensively, but still correctly--as to the coefficients (or changes in coefficients) to be applied to a given sector. This fact leads to the conclusion that in the social sciences, quite unlike the physical sciences, accuracy of observations may not be correlated with the reliability which can be ascribed to them in use.

Some Inferences with Respect to Model Reliability

In the physical sciences, given careful calibration of instruments, systematic error is probably less important with respect to the reliability of a given measurement than is random error. In the social sciences, the same thing probably would be true if there were any way in which the measuring device (the model) could be calibrated in the same strict sense of the term. Unfortunately, however, the above-discussed three influences apply to the calibration as well as to the measurement. For this reason, no absolute base can be provided--or even assumed--that allows the calculation of confidence limits from which reliability may be inferred.

Suppose, therefore, that we begin by stating a series of goals in terms that permit us to assess the reliability of cost-of-fracture measurements:

1. Since absolute measurements of level are so obviously subject to unknown errors, we attempt to cope with error by measuring fracture costs as differences between levels.

2. To the greatest degree possible, we try to achieve independence in determining the values by which we introduce differences into our models. This will at least lead to more randomized errors, especially as to the directions ($\pm$) of the several errors.

3. The I/O Model, by which we make most of our cost estimates, is mathematically a very conservative model. This implies that errors introduced in changing the model's "parameters" (coefficients and final demands) tend to be damped, rather than accentuated, in their impacts on final results.

4. Since the nature of our data gathering procedure makes it heavily dependent upon the interaction of interviewees and interviewers, and since the use of a fairly large number of interviewees is forced by subject matter diversity, we minimize the variety of interactions by minimizing the number of interviewers.

5. To the fullest extent possible, we further reduce the diversity of interactions by consciously briefing the interviewers as uniformly as we can.*

Comparative Reliability of Worlds

As has been noted in other contexts, World I (the peacetime, full-employment, real world) can be reasonably well estimated by the I/O Model as modified to the needs of this study. In World I, technologies are generally estimated by industry experts and finally modified to fit 1978 observations. Final demands are estimated as the full-employment equivalence observed in the 1978 National Accounts. It should be noted in this connection that the demands for capital and other durables are influenced by all of the material failures that occurred, regardless of whether caused by design, by human error, or by catastrophic overload.

The modifications of World I technologies and demands for durable goods to those that characterize the hypothetical no-fracture world (World II) is probably much simpler and easier to accomplish than is the similar modification to the best-practice situation (World III). The proportionate changes in materials inputs that follow from ideal physical characteristics can be directly estimated, given the assumed conditions of World II. Many of the other types of inputs (e.g., transportation) are directly calculable as functions of the changes in material inputs. Others (e.g., inspection) are assumed away by the definitions of World II. In the case of best fracture control practices, however, the actual degree to which they are already being followed in World I is not precisely known, so the basis of the proportionate change from World I to World III is much less definite.

The World I to World II changes in demand for durables are not as clear as the input changes. The nature of these demands in World I is a function of failures which are not altered by World II definitions as well as failures which are. For instance, the destruction of capital by catastrophic forces--e.g., by stresses far in excess of designed loads--as well as by human error and other out-of-scope factors, either must be retained in World II or must be estimated and removed from the World I-World II differences if we are to avoid an overestimation of total fracture costs. The specification of "scope", as described in Chapter II, has alleviated this problem.

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* The last two goals were also promoted by the use of the modified ex ante approach (i.e., the development of row rules), as described in Chapter IV.

"Direction" of Measurement Errors

Although in any problem involving measurement an important aim is always to minimize error, there are many situations in which the direction of the error is significant and should be taken into consideration. In fact, it may be important that effort be made to assure that certain measurements err in a given direction. This study of the cost of fracture has two aspects that are especially significant in this respect.

I/O Model Errors. In order to achieve credibility, the errors made in the I/O Model results should always be on the low side. This is to say that, if we have any choices in establishing the differences between World I costs and those of Worlds II or III, we should always minimize that difference. This course of action assures that the costs of fracture which derive from technological and/or demand factors are always determined as being at least the volume derived. In other words, it is better to underestimate than to overestimate the technical and demand-related costs of fracture.

In generating the I/O model changes, many fracture-related considerations involved capital redundancies for the purpose of avoiding downtime or losses of output. Many of the capital failures which require these redundancies have nonfracture causes; many of the fracture-related causes may still be outside of project scope (human error, etc.). The remainder of the failures, those which should be ascribed to fracture within design, has been made as small as possible, given available information. We consciously strive, in other words, to minimize our estimate of the costs of preventing fracture.

Supplementary Model Errors. The costs that society bears because fractures have occurred are both visible and subject to considerable sociopolitical sensitivity. The events caused by or ascribed to fracture--especially such events as the DC-10 crash or the Kansas City Hyatt Hotel collapse--shock because of their catastrophic nature. They should not be played down; in fact, it is important that steps be taken at once to assure that they never recur. Credibility of measurement therefore requires that these costs be estimated on the high side--that we maximize their importance within the limits supported by our data.

Summary. In interpreting these two sets of costs, we should view them in the following ways:

- The costs to society in order to prevent fractures from occurring are at least this much.
- The costs to society because fracture events cause injury and destruction can be as great as this.

In this way we avoid the two dangers of (a) exaggerating the technical significance of fracture-related activities, or (b) understating the human and social importance of fracture-caused events.

General Note on Sensitivities and Errors

Before taking up questions of model sensitivity and probable errors of measurements, it is important to note that some estimates of error in this study cannot be approached with the same perspective as would the measurement of physical parameters. The "Observed/Observer Problem" referred to above is not the only difficulty faced in this endeavor. Additionally, this entire modeling approach is still a pioneering effort: the application of I/O modeling to problems such as "The Cost of Fracture" is still an evolving field.

Furthermore, while the present study has benefitted from the experience gained in the earlier "Cost of Corrosion" project, that earlier effort has been modified by the development and application of a different--and more internally consistent--data collection procedure. Just as specific procedures have been altered, there has also developed a need for further analysis of the types of errors which may be introduced in applications of the model. It is clearly desirable that we conduct a detailed investigation of the individual and cumulative effects of error introduced by estimated changes in coefficients, outputs, final demands, and other parameters of the model. Such a study should be undertaken, but was not possible given the resources of this program; it is more reasonable that we undertake this type of evaluation separately.

Sensitivity of the Model

The I/O model, as noted above, is very conservative in its structure. This is to say that a datum error anywhere in the central model tends to be diluted and diffused by the complex interactions within the overall modelling program. As a result, even a large error in a single cell often has a small proportionate impact on the model's output. The technical note that follows elaborates on this basic characteristic of the Battelle model as it is being used in this study.

Technical Notes on Model Sensitivity*. Though we cannot use physical-mathematical analogies to assess the reliability of the model's results, we still may exploit them to show how errors in particular parts of this model will propagate.

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* These technical notes are based upon analyses by Professor A. Brody, of the Hungarian Academy of Science, and by Dr. E. Passaglia, of the National Bureau of Standards. Professor Brody was a visting scholar at Battelle during the initial stages of this project. However, responsibility for the final combination of their inputs remains with the authors.

By assigning standard errors to initial observations and data, we will be able to derive standard errors for the computed results and determine whether such errors in data will accumulate, remain the same, or tend to be canceled out during computation. To do this, we must separately consider the constituent parts of the computation, because separable assumptions will be warranted for different bodies of data going into the computer.

The final results (sector total outputs) are produced by multiplying an inverse matrix (the reliability of which will be discussed later) by the vector of noncapital final demands. We may properly assume that the expected (average) error of the component elements of final demand is small, but that a certain error dispersion, d, (a standard error probably up to $\pm$ 10 percent) may be anticipated in such a way that errors in any one component will be independent of errors in other components.

Probability theory now teaches us that, because total output is a nonnegative algebraic combination of the components of the noncapital final demand vector, the resulting quantities will be free of error (their expected error will remain small) and their dispersion will vary inversely with the square root of the number of component elements:

$$\text{resulting dispersion} = d/\sqrt{n}$$

Since n is the number of sectors in the model--in our case, 150--it follows that $\sqrt{150} \simeq 12$. This is to say that the reliability of the results will significantly improve over the reliability of the final demand estimates. As a matter of fact, we know from the law of large numbers that the distribution of the errors of the results will be practically Gaussian, regardless of the shape of the distribution of the initial errors in the final demand vector*.

In this respect, therefore, the computation can be considered "self-improving" and practically exact in the first three significant digits it produces. The estimates for final demand can be kept within a 10 percent standard error and these errors would therefore be reduced by the computation to one-twelfth their original size.**

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* When the number of sectors exceeds 60, we have every right to consider it as a fairly large "sample", and we know that the sum of independent distributions tends strongly toward the Gaussian distribution, whatever their original quality.

** The expression for the resulting dispersion is only a special case. As noted by Passaglia, this result is realized only if all elements of final demand, as weighted by the coefficients of the inverse matrix, are equal, and if each element of final demand has the same fractional error. For purposes of general discussion, Brody's overall expression is sufficient; however, and more detailed analysis would require, at a minimum, examination of the effect of realistic deviations from the simplifying assumptions.

In this connection, attention is called to the fact that the non-capital final demands do not change significantly for the majority of sectors. To be sure, there are several individual sectors in which changes occur--although not to the extent noted in the earlier "Cost of Corrosion" study--and these contribute to the measurement of the total costs of fracture. As is the case throughout all manipulations of the model, it must be realized that adjustments for World II or World III are made in terms of the difference from a given World I value. Hence, for example, World II final demands are not "measured" (with an error range) and subtracted from corresponding World I final demands; they are determined first as a difference--a conservative fractional increase or decrease--and the World II value is the derived result. Thus any uncertainty in the value of a given World II final demand is not magnified by comparison with the World I - World II difference, but, rather, is reduced in significance by the comparison.

Turning now to the question of errors in the flow and stock matrices (i.e., the A matrix and the B matrix), a new element is introduced. Here we have to distinguish between two types of error.

The first type can be considered purely random and unbiased, again with an expected average value of zero. This stems from the nature of assessment errors in coefficient changes. These will be truly independent and, as will be shown, they cause an error propagation that maintains almost the same relative size of errors throughout our computations. Therefore we can state that, if we assign a 10 or 20 or 50 percent standard deviation to the initial data changes from World I to Worlds II and III, almost the same order of standard deviation will be reproduced in the results.

There also exists a second type of error that is biased, though it affects only a particular data set connected to the stock matrix: that of the changing capital replacement needs which are derived from useful life considerations (i.e., the U matrix). Here the situation is more complex. Although certain mathematical limits can be worked out, these seem to be much too coarse to be helpful. Therefore, an actual sensitivity analysis promises to be much more informative. Besides changes in average useful life, the sensitivity analysis should be run with changes in values for maximal and minimal life spans. Besides the already discussed qualitative problems, the outcome of computations will also hinge considerably on our judgments as to the changes in useful life that occur as we move between the different worlds.

Attention is also called to the fact that there could be a general tendency for the technological changes introduced into the A, B and U matrices to understate the costs of fracture. This derives from the fact that all cells that should change might not be altered by the data gathering process. In a study of this complexity, the limited project resources would usually be used to change first those sectors considered most fracture relevant; and, if resources are not available to treat every sector, some that should change may not. The same would be true of specific cells in a given row or column: attention would be directed first to the most fracture relevant, and some of the less important cells may not be changed. Although some of the changes that are introduced might err in the direction of overstating fracture costs, others err in the opposite direction. Thus there will be a tendency for "active" errors to cancel out, while "passive" errors will cumulatively increase the degree of underestimation of costs.*

In summarizing this technical note, we can say that noncapital final demands will introduce almost no overall error into the model's output (although, as noted earlier, some errors might be introduced into the estimate of differences), and that error will be reduced by a factor of about twelve. The errors introduced by changes in the A and B matrices will be those of the row data used in determining the changes themselves; they will remain <u>proportionately</u> the same throughout the computation. The most important errors from a computational point of view are those introduced by changes in useful lives, which deserve further discussion.

We state useful lives as a range, the upper limit of which probably is more nearly a function of technological obsolescence than of anything else. Certainly, considerations of fracture will primarily affect only the lower limit of that range. Shifts in the lower limit will enter the replacement matrix through reductions in the number of replacement rates (each a reciprocal function of the involved year of life) that are averaged. Thus, the average will shift by proportionately less than will the number of years themselves. Nevertheless, because the replacement rate is a reciprocal function, there is a tendency for errors in useful life to <u>grow</u> in computation. It is, however, unlikely that, in the aggregate, this error will lead to an <u>over</u>statement of fracture costs, given the general bias toward <u>under</u>statement in the A, B and U matrix changes.**

<u>The Supplemental Models</u>

The Supplemental Models are potentially quite different from the I/O model in terms of reliability. As has been pointed out in other connections, the Supplemental Models relate to the I/O model in two different ways: (a) they measure imputed (nonresource) costs which are not measured at all in the I/O model, and (b) they measure some resource flows that may either supplement or duplicate I/O model results. The first set of measurements are independent of the I/O model insofar as reliability is concerned. The second, however, is not; and it may introduce additional errors into the final results through the double counting of particular resource flow.

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* It is noted, however, that the emergence and application of the row rule approach (see Chapter IV) reduces the amount of understatement that might have occurred. These rules are, however, all very conservative; hence, the final results probably are still understated.

** These discussions, so far so they concern the U matrix, are more relevant to the corrosion than they are to the fracture study. As will be recalled from Chapter IV, no changes have been made in the U matrix from World I to establish World II or III conditions.

Events vs. Useful Lives. When we consider all the fracture related events that occur during a given year, it is obvious that many of them are routinely taken into account by business. For example, the fact that particular items (especially capital items) break or tear in the regular course of business is taken as a matter of fact. An inventory of spares will be kept on hand so as to minimize down time or inconvenience. It does not matter in the business context whether the particular failure is ascribed to human (operator) error, to accidental overload, or to a material failure of the kind with which this study is concerned, namely, "unintended fracture".

For many durable but fracture-potential items, business normally takes account of fracture rates (regardless of cause) in terms of: (a) intermediate activity, such as maintenance and repair, over-inventories of breakable inputs, or insurance; (b) redundant capital or (c) shortened useful lives, i.e., earlier replacement. To the extent that our coefficient changes take full account of all these practices, the I/O tables will account for all relevant resource flows and the corresponding outputs of the supplemental models are redundant. It should be noted, however, that this is not true of any imputed costs.

Costs of Medical Care. The medical care of persons injured in fracture caused events is completely covered in the full-employment I/O table for World I. To the extent that the fracture-related events occur in industrial settings, these costs show up as intermediate inputs into the relevant industries from sector 21.07 (Medical and Health Services) and, perhaps, from sector 5.09 (Drugs). To the extent that the accidents are not industrial, the costs would show in the final demand subvectors (PCE or Government Expenditures) on the same row(s).

In the Supplemental Models, medical costs are part of the output of the Injury Cost Model. To the degree that these estimated costs are complete, they can be subtracted from the World I totals to obtain corresponding costs in Worlds II and III. However, the precision of this value is a function of the separation of "all" events into "fracture-caused" and "other" events.

The problem of separation has been taken into account by establishing ranges of frequencies for all types of events. This has already been discussed in Chapter V, with greater detail provided in Appendix E. If we take the high estimates, only, as our measure, we can be sure that they certainly equal (and are likely to exceed) the totality of these costs. Total injury costs--estimated to be $132.8 million--include both medical services and drugs, plus other, miscellaneous costs. The total outputs of these two sectors in the I/O table (World I) are estimated to be $82.8 billion (drugs + medical services = $12.8 billion + $70.0 billion = $82.8 billion). Thus, the Supplemental Models' results account for no more than 0.2 percent of the total. This is typical of the relationship between the two models.

Property Losses vs. Final Demands. When a fracture caused event leads to a loss of property--cargo/content, the fractured item itself, or other subsequent destructions--one must make up for that loss. If the destroyed property is a capital item, final demands must include its replacement, probably through the mechanism of the replacement (R) matrix or of the capital/output ratio. To the extent that these matrices are already properly adjusted in going from the I/O table of World I to those of Worlds II or III, the property losses from the Supplemental Models will tend to be redundant.

To the degree that the destroyed property was not technically shown as a part of World I--as, for example, the loss of petroleum moving through a pipeline from well to refinery--either it would result in an underestimate of resource costs, or it would have to be added to World I final demands as an entry into the new "loss" column. This latter has, in fact, been done.

Sensitivity of the Supplemental Models. Given the relatively small sizes of costs measured by the Supplemental Models and the minimum/maximum ranges within which they have been determined, it is safe to assume that the Supplemental Models do not contribute significantly to the error of the total cost measurement. For that reason they will not be considered further in this context.

Overall Reliability of the I/O Model

It should be noted in this connection that changes were made in the I/O procedure from that outlined in the Phase I report* (see Chapter IV), and that these changes affected the proposed procedure for determining the model's reliability. For this reason, we have undertaken this task in a quite different fashion.

Data Collection

In collecting the data for column-specific adjustments of World I coefficients, it was planned to record eight kinds of information on the data forms. The first six of these** identified and recorded the data. The seventh item (authority for the change) was to provide the basis for assigning sector reliability tags; and the last (further explanations) was primarily expository and clarifying. Only the seventh item was to be used in assigning reliability tags; however because of changes in the method of obtaining

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* The Economic Aspects of Fracture in the U.S. Economy: Phase I Report, Battelle Columbus Division, December, 1980.

** (1) Type of data and place acquired; (2) field interviewer; (3) identification of source; (4) affected cells; (5) nature of the change; (6) proportional change.

information, these data were only partly collected. For the 60 sectors that were treated as column-specific, all the change data were based on the industry experience of the informant or on results of research carried out for industry sponsors. These sectors therefore can be assigned relatively high reliabilities--i.e., probability ratings of ± 10 percent--with respect to the changes (World I to Worlds II and III) in their A matrices. The other 90 sectors were less important in fracture terms and were adjusted by means of row rules based on the collected data and on the judgment of Battelle senior scientists. Since these changes did not have the benefit of as much direct industry contact (even though the sources of the adjustments were eminently qualified to provide it) we will arbitrarily assign them reliability ratings of ± 20 percent.

Confidence Ranges

The technical notes (see above) imply that the probability ratings assigned to the sectors are essentially unchanged in their impact on the model. We assume, therefore that they become:

$$\pm \sqrt{\frac{60 \times (.10)^2 + 90 \times (.20)^2}{150}} = \pm\ 16.7 \text{ percent}$$

This average 16.7 percent probability then is assumed to characterize all the coefficient changes.

Since the noncapital final demands change by very little, and since the total output errors calculated from final demand are "self-improving", to use Brody's language, we assign a ± 5 percent error to the effects of stipulated final demand. The capital demand involves the B and the R matrices* and, under these circumstances, should be those of the B matrix changes (± 16.7 percent) only. Again, we assume that the average error will apply. Our weights, based on World I relationships, will be 15 percent capital and 85 percent stipulated, giving for the average final demand confidence limits:

$$\pm \sqrt{\frac{85 \times (.05)^2 + 15 \times (.167)^2}{100}} = 7.9 \text{ percent}$$

Assuming the worst, then the overall confidence range would be ± (1.167 x 1.079)-1 or ± 26 percent. In this connection, however, attention is called to Brody's final remarks (see above) about the error effects of the matrix adjustments. After pointing out that all changes that should be made may not be made, he concludes the paragraph with:

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* Note that, since we did not introduce changes into the useful lives, the biases through the U matrix (emphasized by Brody) do not enter.

"Although some of the changes that are introduced might err in the direction of overstating fracture costs, others err in the opposite direction. Thus there will be a tendency for 'active' errors to cancel out, while 'passive' errors will cumulatively increase the degree of underestimation of costs."

It appears therefore that in the final balance, the true values of these estimates would fall somewhere above those given, but below the given values multiplied by 1.26.

Furthermore, since the same data bases and procedures entered all adjustments, the errors in total costs of fracture and presently reducible costs of fracture are the same. It is not possible to assign an error range to World IV and future reducible costs of fracture; but it is undoubtedly greater than ± 26 percent.

Final Assessment of Fracture Costs

To conclude this assessmentof the costs of fracture in the United States, it is necessary that we take the cost breakdown of Table 27, above, and estimate a most likely level of costs, using the just-established confidence range. It must be emphasized throughout this assessment that, for two reasons, we feel certain that the model results understate the costs:

- Brody's point concerning the tendency of the World adjustments to understate in the aggregate
- The deliberate policy, adopted throughout the adjustment process, of working at the low end of indicated ranges of coefficient change.

We still do not know the most likely levels of I/O model results as they apply to World II and III or the resultant World I - World II and World I - World III differences. However, the conservative and consistent approach to coefficient changes would indicate that the calculated differences in model outputs would be minimized; i.e., the actual differences in outputs could be no less than those calculated or as great as 1.26 times those calculated.

Here again a much more detailed assessment of individual errors and a tracking of such errors through the model would be instructive, and should be carried out in the context of general applicability of the I/O technique. Lacking that, a "most probable error"--averaged over all individual sectors--can be taken at half the value of the expected (positive) error band. Thus we can set the total cost of fracture 13 percent above the level calculated from the model.

With respect to the Supplemental Models, there is no way in which confidence limits can be set. The data bases for these models are of such variable quality, detail, and completeness that they cannot be evaluated. The Supplemental Model Task Team determined the absolute upper limits of every possible range: that is, they eliminated from consideration only those events that obviously had to be outside of scope, and assigned maximal rather than minimal values to events. Still, we have no way of knowing whether the results do, in fact, overstate these supplemental costs. Since every effort has been made to err on the high side with respect to these costs (in sharp contrast with the technical costs from the I/O Model), we will assume that these costs, also, are subject to the same correction (± 13 percent) applied to the I/O results. Regardless of how they are treated, these supplemental costs remain relatively small.

The analysis and forecast of World IV conditions, i.e., the ultimate future results of fracture-related research and development, were subject to the same intellectual constraints imposed on the I/O Model. Since this, too, represents a set of technical considerations, every effort was made to understate the benefits of future research. There is absolutely no basis for assigning confidence limits to World IV results. However, for convenience, we will apply the same +13 percent adjustment to these estimates.

Adjusted Costs of Fracture

In Table 28 we have taken the Total Costs of Fracture (displayed in Table 27) and adjusted them for understatement. This figure has been distributed over its four component elements and also related to 1978 GNP (real world, full employment) as calculated by the model for World I.

This places the most likely total cost of fracture at $99.0 billion, or 4.4 percent of GNP. Of this, $29.1 billion is treated as presently reducible (through education, technology transfer and adoption of best practices) and $23.4 billion is treated as future reducible (through research plus education, etc.). In other words, $52.5 billion (or 53.1 percent) of these costs are considered reducible and the remainder, $46.5 billion (or 46.9 percent) are considered to be totally irreducible by presently known means. If anything happens to further reduce that remainder, it will involve breakthroughs in areas that would be totally surprising to today's community of fracture researchers.

TABLE 28. MOST LIKELY VALUES. COST OF FRACTURE IN THE UNITED STATES, 1978

Elements of Fracture Cost	Adjusted for Confidence* ($ million)	Percent of "All Costs"	Ratio to GNP**
All Costs	99,019.1	100.0	.0441
Presently Reducible	29,108.0	29.4	.0130
Presently Nonreducible	69,911.0	70.6	.0312
Future Reducible	23,433.7	23.7	.0104
Future Nonreducible	46,477.2	46.9	.0207

Source: See Notes.

Notes:

* Column totals from Table 27 multiplied by 1.13.

** 1978 Full Employment GNP estimated to be $2,243.0 billion (see Chapter VI).

Details may not add because of rounding.

ADDENDUM TO CHAPTER VIII. NORMALIZED ANALYSES

As an integral part of the Corrosion Study, a set of so-called "Industry Indicators" was computed for the purpose of supporting normalized analyses of sectoral association with corrosion. Experience with the use of these indicators convinced several persons, both at the National Bureau of Standards and at Battelle, that they did not fully or effectively serve their intended function. It was therefore decided to forego the calculation and use of Industry Indicators in the Fracture Study.

One element that was proposed by the Bureau, in part for the purpose of supplying data that would substitute for the Indicators, was the so-called "World IV" projections, discussed in Chapter VII, above. Another approach to this same purpose involves special manipulations of row and/or column data with the intent of isolating technological fracture-relevance from demand-driven fracture impacts.

Brief discussions follow of the normalization approaches to the separation of technology and demand. In turn, they will be followed by a few selected analyses using these data and methods.

In constructing a transactions (dollar flow) table for the economy, it's A matrix columns are multiplied by the total outputs already derived by means of the inverse and the final demand. This is to say that

$$x_{ij} = a_{ij}X_j$$

Specifically, to obtain $x_{1,2}$, the coefficient $a_{1,2}$ is multiplied by X_2; and to obtain the column of values x_{i2}, every a_{i2} is multiplied by X_2. If we symbolize the intermediate dollar flow matrix as [x] and designate the Worlds by subscripts I, II and III, we would indicate this derivation:

$$[x]_I = A_I X_I$$

$$[x]_{II} = A_{II} X_{II}$$

$$[x]_{III} = A_{III} X_{III}$$

We have already noted that both the row and column relationships in the several difference tables (I-II, I-III, III-II) are complicated somewhat by the fact that direct changes in coefficients are modified because of indirect changes in demands, that is, because $X_I \neq X_{II} \neq X_{III}$. In order to eliminate this source of confusion and to simplify both row and column comparisons between worlds, we have normalized the technological relationships between worlds by the following change in derivations:

$$[x]_I^* = [x]_I = A_I X_I$$

$$[x]_{II}^* = A_{II} X_I$$

$$[x]_{III}^* = A_{III} X_I$$

Note that while World I transactions values are unchanged, those of Worlds II and III are made directly comparable with World I and with each other by the substitution of X_I for both X_{II} and X_{III}. Now, when the columns are compared in terms of the social savings entries (SS*) and the rows are compared in terms of their respective total intermediate outputs (TIO*), the column comparisons are no longer complicated by changes in demand nor the row comparisons by the indirect effects of technological changes. These differences between worlds are brought together in Table 29 and will be used in analyses of selected sectors.

In Table 29, the normalized data for technology are found in columns 2, 4, and 6. Column 2 contains the normalized dollar social savings difference for World I-World II; column 4 contains the normalized dollar savings difference for World I-World III; and column 6 contains the normalized difference for Worlds III-II. Set in our cost-of-fracture terminology, we can say that these three columns show the technologically normalized values of total cost, presently reducible costs, and presently nonreducible costs. In the language used in connection with the Indicators, these technologically normalized costs are the "direct" cost of fracture.**

The normalized data for the analysis of demand are found in columns 1, 3 and 5 of Table 29. The World I-World II difference is in column 1; the World I-World III difference is in column 3; and the World III-World II difference is in column 5. These would be total costs, presently reducible costs and presently nonreducible costs, respectively. In the terminology of the Indicators, these would be "indirect" costs of fracture.**

Analysis

We may now illustrate analyses of these normalized relationships in terms of four illustrative sectors with data taken from Table 29. These data are shown in Table 30.

Sector 2A04, Underground Coal Mining

In this sector, the need for additional inputs (particularly, of labor) in order to achieve best practices makes presently nonreducible costs appear greater than total costs in real world terms. This paradox is easily resolved by the understanding that best practices are not strictly economic in the short-term sense. Since best practices here relate to savings of life and preservation of resources that are at risk in the real world, direct costs in

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* Normalized values are indicated by the asterisks.

** It should be noted that these values are all "total" in the Indicator language. There are no "per unit" values calculated here. If any are needed, they can be obtained by dividing each sector's values by X_I.

TABLE 29. DATA FOR ANALYSIS OF NORMALIZED FRACTURE COSTS

SECTORS	(1)*	(2)	(3)	(4)	(5)	(6)
1.01 LIVESTK+LIVESTK PRODUCTS	373.77	-429.21	160.60	-212.37	213.16	-216.85
1.02 FIELD + ORCHARD CROPS	596.75	-399.97	109.86	-198.20	486.89	-201.77
1A03 FORESTRY PRODUCTS	21.93	-6.29	-334.50	-3.08	356.44	-3.21
1B03 FISHNG,HUNTNG,TRAPPING	4.60	-20.70	2.30	-6.94	2.30	-13.77
1.04 AGRI, FORST + FISH SERVC	9.78	-6.23	4.64	-3.76	5.14	-2.47
2.01 IRON + FERROALLOYS ORES	182.36	-78.92	119.70	-27.90	62.66	-51.02
2X02 NONFERROUS ORES MINE	55.59	-44.90	29.25	-18.06	26.34	-26.85
2A04 UNDERGROUND COAL MINE	94.48	-253.15	262.69	266.50	-168.21	-519.65
2B04 STRIP COAL MINING	82.95	-65.69	98.89	-31.52	-15.93	-34.17
2C04 OTHER COAL MINING	.38	-1.27	.27	-.60	.11	-.67
2A05 CRUDE PETROLEUM	418.43	-883.91	208.98	-359.79	209.45	-524.12
2B05 NATURAL GAS	1.19	-178.43	.60	-72.69	.60	-105.74
2.06 STONE + CLAY MINING	537.40	-119.91	-16.69	-53.91	554.09	-66.00
2.07 CHEM + FERTLZR MINERALS	60.99	-15.95	26.47	-6.54	34.52	-9.41
3A01 BEVERAGES	76.71	-1358.39	22.74	-361.23	53.97	-997.16
3B01 OTHER FOOD+KINDRED PRD	390.33	-2593.04	175.04	-1215.64	215.29	-1377.41
3.02 TOBACCO MANUFACTURES	10.85	-83.99	.00	-.46	10.85	-83.52
3X03 LEATHR+LEATHR PRD	9.32	-68.36	4.72	-1.14	4.60	-67.22
3X05 FAB,YARN,THRD+SFLOOR COV	133.51	-1001.02	58.26	192.21	75.25	-1193.23
3A07 METAL TIRE CORD	335.46	-45.94	-26.16	-11.76	361.63	-34.18
3B07 OTHER CORD+MISC TEXT PR	231.14	-50.50	-4.61	-10.23	235.74	-40.26
3X08 APPRL+MISC FAB TEXT PRD	41.86	-234.90	20.71	-92.23	21.16	-142.68
4.01 SAWMILLS + PLANING MILLS	879.84	-161.91	440.41	-62.40	439.43	-99.50
4.02 VENEER,PLYWOOD+LAM WD	37.91	-216.18	18.87	-91.11	19.04	-125.07
4.03 OTHER LMBR+WD EX CONTNRS	244.92	-203.86	117.53	-73.28	127.39	-130.59
4.04 WOODEN CONTAINERS	19.88	-44.41	.76	-18.78	19.12	-25.63
4XA5 WOOD FURNITUR+FIXTUR	13.07	-484.68	6.48	-208.91	6.58	-275.78
4XB5 METAL FURNTR+FIXTURES	2.57	-200.65	1.16	-80.92	1.41	-119.72
4.07 PULP+PAPR PRD EX CONTNRS	481.99	-1271.09	228.76	-567.75	253.23	-703.35
4.08 PAPERBRD CONTAINERS+BOX	230.02	-180.85	19.41	-52.18	210.61	-128.66
5.01 PETROL REFNG + RELTD PRD	1763.56	-1891.47	439.09	-860.24	1324.47	-1031.22
5.02 PAVING MIX+ASPHALT PRD	7.21	-44.32	3.92	-19.38	3.29	-24.94
5.03 INDUSTRL INORG+ORG CHEM	457.38	-1374.98	-65.08	-527.77	522.46	-847.21
5X04 AGRICULTURAL CHEMICALS	11.11	-80.35	4.99	-22.52	6.13	-57.84
5A06 ADHESIVES	31.80	-121.38	.53	-44.00	31.27	-77.38
5B06 OTHER CHEMICAL PRD	31.72	-67.47	6.83	-25.37	24.89	-42.09
5.09 DRUGS	7.47	-152.51	2.99	-52.21	4.47	-100.29
5X10 CLEANING+TOILET PREP	11.72	-217.44	5.10	-83.35	6.61	-134.09
5.12 PAINTS+ALLIED PRD	23.40	-137.84	11.10	-60.80	12.31	-77.05
P.07 PLAST MATR,RESIN+SYN RUB	1769.39	-97.11	1070.97	-16.21	698.41	-80.90
P.08 ORGANIC MANMADE FIBERS	200.10	-114.24	-156.08	-9.50	356.18	-104.74
P.13 TIRES+INNER TUBES	20.10	-1825.11	9.80	-43.11	10.30	-1782.00
PA14 INDUSTRIAL RUBBER BELTS	45.54	-90.28	13.94	-16.01	31.60	-74.27
PB14 OTHER RUBBER PRD	12.38	-140.31	5.96	-36.48	6.42	-103.83
PA15 PLASTIC PIPE	14.47	-573.70	5.94	-83.45	8.53	-490.25
PB15 PLASTIC CONTAINERS	33.75	-261.35	14.36	-89.20	19.40	-172.15
PC15 OTHER MANF PLASTIC PRD	75.44	-440.42	14.38	-151.58	61.06	-288.83
6A01 FLAT GLASS	10.63	-168.14	5.17	6.48	5.46	-174.62
6B01 GLASS CONTAINERS	69.86	-506.63	26.62	-57.05	43.25	-449.58
6C01 AUTO+TRUCK WINDSHIELDS	5.73	-36.06	2.87	-3.17	2.87	-32.89
6D01 OTHER GLASS PRD	10.32	-181.28	4.81	-29.95	5.51	-151.33
6.02 CEMENT+LIME+GYPSUM PRD	94.89	-62.75	43.33	-23.23	51.57	-39.52
6A03 STR CLAY PRD EX REFRAC	11.57	-306.70	5.95	-59.76	5.62	-246.94
6B03 STR CONCRFT PRD+CEMENT	396.48	-852.05	-725.40	-218.77	1121.88	-633.29
6C03 POTRY+WHTWR+PORCLN PRD	4.64	-103.22	1.96	-28.16	2.69	-75.06
6D03 CLAY+NCLAY REFRACTORIES	628.61	-583.27	66.84	-321.01	561.77	-262.27
6A04 ABRASIVES INC GRIND WH	23.05	-75.84	12.11	-21.06	10.94	-54.78
6B04 OTHER NONMET MINERAL PRD	17.21	-61.02	9.70	-22.91	7.51	-38.11
7A01 IRON,CARBN STEEL+COKE	20202.08	-1266.53	8113.47	-1462.98	12088.61	196.45
7B01 ALLOY STEEL	1179.27	-90.36	372.32	-60.56	806.94	-29.80
7C01 STAINLESS STEEL	945.64	-47.16	358.37	-28.31	587.27	-18.85
7.03 PRIMARY ALUMINUM	3660.03	-545.55	1356.40	-251.85	2303.63	-293.70

* See Legend, End of Table

TABLE 29. (Continued)

SECTORS	(1)*	(2)	(3)	(4)	(5)	(6)
7X04 OTHER NONFERROUS METALS	5471.96	-2743.79	1762.01	-1096.24	3709.95	-1647.55
8.01 METAL CANS	91.83	-1055.70	32.12	-395.23	59.71	-660.48
8.02 METAL BARRELS,DRUM+PAILS	7.33	-230.85	3.13	-82.41	4.21	-148.44
8.03 MET SANIT+PLUMBING PRD	5.01	-33.19	2.61	-5.37	2.40	-27.83
8.04 NONELEC HEATING EQUIP	12.04	-104.95	5.66	-21.98	6.38	-82.97
8A05 STRUCTURAL METAL	6.52	-1856.21	3.31	-690.68	3.21	-1165.54
8B05 BOILER SHOP PRO	5.55	-359.76	2.33	-133.70	3.23	-226.06
8C05 OTHER FAB STRUCTRL PRD	61.51	-2274.39	26.73	-849.26	34.78	-1425.13
8.06 SCRW MACH PRD+STAMPNGS	679.58	-1874.05	46.55	-731.02	633.02	-1143.02
8.07 FABRICATED METAL PRD	130.52	-355.96	58.46	-80.36	72.16	-275.60
9.01 ENGINES + TURBINES	61.19	-766.94	35.79	-308.78	25.30	-458.16
9.02 GEN INDUS MACH+EQUIP	150.93	-1545.49	74.90	-585.55	76.03	-959.94
9.03 MACHINE SHOP PRD	108.63	-314.32	57.25	-115.42	51.38	-198.90
10.01 FARM MACHINERY	26.30	-418.57	13.18	-159.48	13.12	-259.09
10.02 CONSTRUCTION MACHINERY	251.53	-1055.29	126.49	-387.95	125.04	-667.34
10.03 MINING MACHINERY	12.28	-117.07	6.70	-42.48	5.59	-74.59
10.04 OIL FIELD MACHINERY	22.19	-81.07	10.11	-29.64	12.08	-51.43
10.05 MTRL-HNDLNG MACH EX TRUC	313.17	-504.16	157.03	-184.14	156.14	-320.02
10.06 INDUST TRUCKS + TRACTORS	21.06	-183.46	10.60	-66.86	10.45	-116.60
10.07 METAL WORKING MACHINERY	612.36	-525.63	66.11	-186.59	546.25	-339.04
10.08 SPECL INDSTRY MACHINERY	200.22	-773.70	88.67	-279.21	111.55	-494.49
11.01 MOTOR VEHICLES + PARTS	1127.15	-9422.88	563.72	-2709.12	563.42	-6713.76
11.02 AIRCRAFT + PARTS	61.99	-5095.04	30.99	-27.41	30.99	-5067.64
11.03 SHIP+BOAT BLDG + REPAIRS	46.45	-444.32	23.22	-77.85	23.22	-366.46
11.04 LOCOMS+RAIL+RPD TRNST	33.83	-395.97	16.93	-148.54	16.90	-247.43
11.05 CYCLES,TRAILERS, ETC	20.53	-433.64	10.27	-158.95	10.26	-274.69
12.01 ELEC MEASURING INSTRUMTS	12.44	-30.93	4.85	-12.08	7.59	-18.85
12A02 ELEC MOTRS+GENRTRS,POWPL	1.37	-17.33	.68	-5.31	.68	-12.02
12B02 OTHER ELEC MOTRS+GENRTRS	58.64	-338.71	29.24	-115.87	29.40	-222.84
12.03 INDUS CONTRL,TRANSFM,ET	83.63	-101.61	41.70	-10.46	41.93	-91.16
12.04 ELECTRIC LAMPS	6.88	-87.74	3.34	-35.56	3.55	-52.18
12.05 LIGHT FIXT+WIRING DEVICE	95.11	-379.99	47.55	-138.83	47.56	-241.16
12.06 ELECTRNC COMPNTS+ACCESS	23.79	-191.10	11.02	-84.79	12.77	-106.31
12A07 X-RAY EQUIPMENT	3.82	-9.47	.65	-2.77	3.17	-6.69
12B07 OTHER MISC ELEC MACH	59.60	-206.36	29.10	-73.94	30.49	-132.42
13.01 SERVC INDUSTRY MACHINERY	32.83	-619.70	16.18	-212.28	16.65	-407.43
13.02 HOUSEHOLD APPLIANCES	5.25	-519.99	2.62	-180.87	2.62	-339.11
13.03 RADIO,TV+COMMUN EQUIP	40.68	-294.83	20.08	-53.68	20.60	-241.15
14A01 FRACTURE CONTROL INSTR	10.68	-25.74	3.28	.51	7.40	-26.25
14B01 OTHER SCNC INSTR,ETC	49.15	-553.99	22.98	-186.10	25.17	-367.90
14.02 MED,SURGCL,DENTAL INSTR	15.00	-138.02	7.05	-42.42	7.96	-95.60
14.03 WATCHES,CLOCKS + PARTS	2.76	-31.94	1.35	-9.36	1.40	-22.58
14.04 OPTICAL+OPTHALMIC GOODS	5.50	-56.56	1.86	-24.63	3.64	-31.94
14.05 PHOTO EQUIP + SUPPLIES	20.41	-134.53	9.86	-37.60	10.55	-96.93
15.01 COMPUTING+RELAT MACHINES	98.77	-165.96	47.37	-66.67	51.41	-99.29
15.02 OTHR OFFICE+BUSIN MACH	105.36	-94.48	50.61	-36.18	54.75	-58.30
15.03 OFFICE SUPPLIES	43.34	-26.84	4.07	-12.23	39.27	-14.62
16.01 ORDNANCE + ACCESSORIES	6.83	-386.28	2.97	-113.64	3.86	-272.64
16A02 SPORTING GOOD+TOYS	.27	-279.52	.13	-103.83	.14	-175.70
16B02 OTHER MISC PRD	4.92	-201.01	2.52	-64.22	2.40	-136.79
17.01 RAILROADS+RELATD SERVCS	1031.70	-465.13	297.38	-63.94	734.32	-401.19
17.02 LOCAL+HIGHWAY PASSNGR TR	.01	-332.85	.00	-126.58	.00	-206.27
17.03 MOTOR FREIGHT+WAREHOUSE	1860.90	-540.76	504.04	-191.49	1356.86	-349.28
17.04 WATER TRANSPORTATION	237.51	-332.47	72.88	-105.89	164.63	-226.58
17.05 AIR TRANSPORT	2.99	-652.67	1.44	-69.05	1.54	-583.62
17.06 PIPE LINES	10.27	-27.96	5.11	-10.20	5.16	-17.76
17.07 TRANSPORTATION SERVICES	.35	-10.41	.09	-.07	.26	-10.34
18.01 TELECOMMUNICATION	37.53	-122.59	13.62	-46.33	23.71	-76.27
18.02 ELECTRIC POWER	362.93	-242.34	87.32	-68.15	275.61	-154.20
18.03 GAS	1059.63	-70.05	99.18	-28.79	960.45	-41.26
18.04 WATER + SANITARY SERVICE	34.36	-36.86	14.26	-3.05	20.10	-33.81
19.01 NEW CONST,NONFARM RESID	0.00	-4560.32	0.00	-260.00	0.00	-4300.32
19.02 CONST,NONRESID BUILD	279.40	-2896.72	-69.63	-135.73	349.03	-2761.00

* See Legend, End of Table

TABLE 29. (Continued)

SECTORS	(1)*	(2)	(3)	(4)	(5)	(6)
19A03 CONST,RAILROADS	13.35	-348.71	-6.60	-109.80	19.94	-238.92
19B03 CONST, PIPELINES	.91	-91.32	-.42	-31.46	1.33	-59.86
19C03 OTHER PU, CONST	11.89	-1814.63	-5.94	-516.41	17.83	-1298.21
19A04 CONST,HIGHWAYS	6.14	-524.03	-.17	162.25	6.31	-686.28
19B04 CONST,BRIDGES	.89	-169.74	-.45	-47.02	1.34	-122.71
19C04 CONST, DAMS	1.34	-28.56	-.67	-7.62	2.02	-20.95
19D04 CONST, ALL OTHER	14.43	-291.85	1.51	-103.50	12.92	-188.35
20.01 WHOLESALE+RETAIL TRADE	313.97	-204.79	149.33	-81.72	164.64	-123.08
20XA2 INSURANCE	26.71	-2.52	10.00	-.92	16.71	-1.59
20XB2 FINANC,REAL EST+ADVERTSG	340.22	-144.30	151.32	37.95	188.89	-182.25
20A05 FRACT RESEAR+DEVEL	806.44	0.00	5.55	-.57	800.89	.57
20B05 OTHER RESEARCH + DEVEL	246.06	-203.32	94.97	-75.05	151.09	-128.28
20C05 ENVIRONMENTAL CLEANUP	87.87	-1.39	43.96	-.46	43.91	-.93
20D05 OTHR BUSNS+PROFESNL SERV	589.08	-103.72	418.10	-50.26	170.98	-53.46
20.06 BUS TRAVEL,ENTER+GIFTS	100.80	-4.18	30.95	-2.07	69.84	-2.11
21.01 PRINTING + PUBLISHING	52.71	-248.63	19.72	-122.53	32.99	-126.10
21.02 RADIO + TV BROADCASTING	.01	-.04	.00	-.02	.00	-.02
21.03 HOTELS + LODGING PLACES	.26	-29.08	.12	-10.75	.13	-18.33
21A04 PERSONAL SERVICES	.83	-6.73	.41	-2.78	.42	-3.95
21B04 REPAIR SERV, EXC AUTO	227.31	-7.11	113.66	-2.69	113.65	-4.42
21.05 AUTOMOBILE REPAIR+SERVC	127.35	-573.43	63.89	-285.07	63.45	-288.36
21.06 AMUSEMENTS	.07	-23.38	.02	-7.44	.04	-15.93
21.07 MEDICAL + HEALTH SERVICE	4.30	-48.52	1.16	-20.23	3.14	-28.29
21.08 EDUCAT SERVC+NONPROF ORG	14.81	-52.07	5.51	-1.04	9.29	-51.03
22.01 POST OFFICE	17.37	-26.24	7.74	-10.74	9.63	-15.50

*(1) = Total Intermediate Output Difference: TIO_{I-II}

(2) = Social Savings Difference: SS_{I-II}

(3) = TIO_{I-III}

(4) = SS_{I-III}

(5) = TIO_{III-II}

(6) = SS_{III-II}

TABLE 30. NORMALIZED DIRECT AND INDIRECT COSTS OF FRACTURE ASSOCIATED WITH SELECTED SECTORS

	2A04 Underground Coal Mining	7.03 Aluminum	11.02 Aircraft and Parts	17.05 Air Transport
Technology (Direct Costs)				
(1) SS^*_{I-II} (TC)	-253.15	-545.55	-5095.04	-652.67
(2) SS^*_{I-III} (PRC)	266.50	-251.85	- 27.41	- 69.05
(3) SS^*_{III-II} (PNC)	-519.65	-293.70	-5067.64	-583.62
Demand (Indirect Costs)				
(4) TIO^*_{I-II} (TC)	94.48	3660.03	61.99	2.99
(5) TIO^*_{I-III} (PRC)	262.69	1356.40	30.99	1.44
(6) TIO^*_{III-II} (PNC)	-168.21	2303.63	30.99	1.54

Notes: * Normalized values from Table 29.

TC = total costs

PRC = presently reducible costs

PNC = presently nonreducible costs

Attention is called to the fact that negative entries in Social Savings differences and positive entries in Total Intermediate Output differences both indicate the same thing: a reduction in resource flows.

World III are substantially higher than in World I, while those in World II are substantially lower.

Moreover, almost all these costs associated with coal mining are directly part of the mining technology. Comparisons of lines 1 and 4 indicate that total direct costs are about three times as great as the total indirect costs. In the case of presently reducible and nonreducible costs, direct and indirect costs move in opposite directions because of the behavior of World III.

Sector 7.03, Aluminum

Since aluminum is a widely used material, it is to be expected that high indirect fracture costs will be associated with it. For all three categories of cost, indirect costs are about 6/1 larger than direct.

Sector 11.02, Aircraft & Parts

In this sector, fracture costs are overwhelmingly direct and presently nonreducible. It must be emphasized, however, that the R&D activities which have the best chance of reducing these costs in the future may not be directly associated with aircraft design, but may relate to characteristics of materials used in their production.

Sector 17.05, Air Transport

Here, again, fracture-related costs are predominantly direct and presently nonreducible.

Intersectoral Comparisons

If we shift attention from the columns in Table 30 to rows 2, 3, 5, and 6, the full benefits of normalization becomes apparent. This entire study has been undertaken for the purpose of guiding future effort--both in R&D and in technology transfer--to reduce fracture costs. Thus, any analyses that improve our understanding of these opportunities are valuable. Ignoring the total costs of fracture, suppose we consider the future choices among just these four sectors with respect to technology transfer (the achievement of best practices) and R&D (the attack on presently nonreducible costs).

Technology Transfer. Without any doubt, the best opportunities for achieving cost reductions through best practices lie with Sector 7.03 (Aluminum), although a great need for technology transfer exists in Underground Coal Mining (Sector 2A04). The decision with respect to division of effort between these two sectors would have to be made in terms of intent: Are we anxious to achieve the highest levels of mine safety, or are we solely concerned with reducing real world uses of resources? If the former, then coal mining would receive more effort; if the latter, then aluminum.

Future R&D. Overwhelmingly, the leading direct opportunities for cost savings through future R&D are related to the aircraft sector. However, as has been noted before, we will have to go "inside" this industry's technology before we can answer the key question: Is it aircraft technology or the characteristics of inputs into aircraft that should be emphasized in this research?

In a near tie for second place for R&D effort, we find the technologies of the two sectors, air transport and coal mining, with aluminum following. However, the indirect fracture costs associated with the demand for aluminum closely follow the direct costs of aluminum.

The example presented for these four sectors have been included for purposes of illustration. The analysis can be extended to all 150 sectors and, to be sure, could be carried out as a guide to the establishment of individual research agendas. Whether the results of this investigation are to be used by Federal agencies or by the private sector, a more individualized inspection of the overall direct and indirect costs--as well as the individual sources of these costs--can provide important insights into the potential benefits of new research or technology transfer programs.

IX. CONCLUSIONS AND RECOMMENDATIONS

The eight preceding chapters have been devoted to discussions of, first, methods of measuring the costs of fracture, second, the data upon which the measurements could be based and, third, the measured costs themselves. Although many inferences concerning the causes and significances of these costs have been drawn, especially in the last four chapters, there has been no attempt systematically to generalize from our findings. It is now time to do that.

In this chapter we will take up, in order, the following four sets of generalizations: first, our findings, conclusions and suggestions concerning the research methods employed; second, a summary of the costs and their implications as to the economic significance of fracture; third, the logical next steps that should be taken to reduce fracture costs in future years; and finally, the manner in which the findings of this research program can be used to facilitate and guide those steps.

Method

The research program employed in this study made use of two dissimilar approaches in an effort to assure coverage of all the relevant contributors to the cost of fracture. On the one hand, the Battelle Input-Output Model of the United States economy was used, in a manner closely similar to its use earlier in the Corrosion Study, to measure the resource costs assumed in order to prevent fracture or to prevent any business losses because of fracture. On the other hand, as a distinct innovation and extension of the measurement, the Supplemental Models were used to measure the nonresource costs of fracture and the resources that were lost or destroyed by fracture-caused events. Much has been added to our understanding of the strengths and limitations of these two approaches.

The I/O Model

The general effectiveness of I/O and the device of simulating Worlds I, II, and III was clearly demonstrated by the Corrosion Study. Therefore, it was the method of choice for this investigation. A way had to be found, however, for dealing with the best practice world (World III) that was as effective as the handling of World II. This was accomplished in the fracture study by treating these two worlds together, at every step, for every sector, instead of completing every step for World II and then returning in an attempt to complete World III. So far as can be determined from the probability analyses of the Model, these two worlds fall within the same confidence limits.

Still another innovation was tested in this study as a means of collecting essential data and putting it into the Model. This was the device of "row rules" (though some were not actually entered by the rows). The complexity of the fracture-cost problem proved so great, compared with the

Corrosion Study, that it would not have been economically feasible to complete data-gathering by the ex ante (column-wise) approach. In fact, if dependence had been placed solely upon sector-by-sector collection of data, it would not have been possible to consider every sector, probably not even half of them. However, by generalizing fracture-related technologies into applications across the rows in blocks of columns, it was possible to (a) utilize the high levels of scientific and engineering skills present in the Battelle Senior Staff, (b) more completely benefit from the information collected (by the columns) on an industry-by-industry basis, and (c) assure that every column sector was fully considered.

In this connection, it should be noted, however, that the row rule approach probably would not have been as effective in the Corrosion Study as it was here. In the case of corrosion--and in any other case where an industry may create a very special and destructive environment for its capital equipment--the column-wise approach always will be best. Nevertheless, any future measurement problem of this sort will benefit from judicious use of this row-wise approach.

Two other improvements should be mentioned which were made in this study: (a) manipulation of the R (replacement) matrix rather than the U (useful lives) matrix in going from World I to Worlds II and III, and (b) dividing single-cell entries in stipulated final demands into two components, purchases of capital goods (by consumers or governments) and purchases of supplies and/or services. If these two devices had been available for the Corrosion Study, it is possible that certain reliability problems would have been lessened.

Taken all together, we feel that the reliability of the fracture study has been significantly improved over that of the Corrosion Study. The reliability of total cost appears to have been about doubled, and that of presently reducible (avoidable) costs increased much more. Any future applications of this approach will be significantly strengthened by these innovations. And, speaking of confidence limits, considerable emphasis should be given the innovations provided (through the contribution of Professor Brody, embodied in Chapter VIII) with respect to the reliability analysis of I/O models. To the best of our knowledge, this approach carries the fracture study quite a bit further in this regard than had been possible at the time the Corrosion Study was evaluated.

The Supplemental Models

With the exception of human injury costs, modeled by T+E and provided under subcontract, none of the Supplemental Models existed before this study. Thus, there had not been any previous systematic study of the costs of accidental events caused by such as fracture or corrosion. We feel that the present investigation performs a valuable service, therefore, by putting these costs into a clear perspective for the first time. There have been, without question, many serious problems raised in this connection by the lack of detail with regard to a full spectrum of events. Nevertheless, with respect to fracture, this lack of detail proved to be no great loss, mainly because the consequences of fracture-related events turned out to be small.

It is noteworthy that the National Safety Council estimated the total costs of automobile accidents (human and property losses) to be on the order of $34.3 billion. We do not have all the details that entered into this estimate, but we know that is includes all kinds of accidents, many of which were caused by other than fracture. Even after deliberately setting frequencies and costs of fracture events at maximal limits, the most that could be ascribed to automobile events caused by fracture was $614 million--less than two percent of the Council's total.

Attention is called also to Table 24 in Chapter VIII. This table shows that total imputed costs of fracture events, estimated by the Supplemental Models, amounted to about 1 percent of the resource costs estimated by the I/O Model. And the cargo losses, estimated by the Supplemental Models and added into stipulated final demands, amounted to less than one-half of one percent of the stipulated final demands. By any measurement, the cost of fracture-related events is very, very small.

This is not to say, however, that the Supplemental Models are unimportant or that these kinds of costs will prove small in every context. It was important to make these measurements because now we can see them in their proper proportion. Regardless of their social value, which may be very great because of pain and suffering, the economic costs of these events is low. In some future measurement of a different set of consequences they may be dominant.

Attention should be called to some other costs that still have not been measured. We have not attempted in this exercise to measure the costs of inconvenience, local losses of business and other local impacts of fracture. For instance, when a bridge collapses, in addition to direct or human losses, there are others which we have not modeled: the time and fuel required to drive to the nearest standing bridge; sales lost because customers are diverted to a now-closer store; and the like. These costs are not easily supported by data. They may or may not be large enough to be significant--we simply do not know.

Important to all our measurements, but more important here because it helps explain the small size of the supplemental costs, is the concept of "fracture within scope". As has been pointed out in several places, there are many nonfracture events; but there are also many fracture-related events that occur because of forces outside the scope of fracture within (or despite) design. When we eliminate all the nonfracture causations, the relevant numbers of events is greatly reduced, even if the second (scope) screening is not carried out.

Summary of Fracture Costs

Referring to the data displayed in Table 28, we can say that total cost of fracture in the United States in 1978, after adjustments for probable underestimation, was $99.0 billion. Of this total, over half (53.1 percent) is potentially reducible, either by education and technology transfer or by R&D that is yet to be undertaken.

In the case of fracture, unlike that of corrosion, the bulk of these costs is technology driven and can be reduced by actions taken within the industry with which they are associated. The rather small remainder consists of costs that are demand driven and are only indirectly affected by the actions of the associated industry.

What Next?

Given the estimates of fracture costs, what remains to be done? There are two paths of action, by which these costs can be reduced. We examine them at this time. But over and above these steps, there are further analyses that are needed to guide these steps, and we will take them up in our final remarks.

Presently Reducible Costs

$29.1 billion of the total cost of fracture are reducible by means of adoption and use of present best practices. This is to say that practices which are already known and used by some sectors should be made known to others, so that they too can achieve best practices in fracture control, prevention or reduction. Since these technologies are already known, little if any R&D needs to be undertaken concerning them. What is required is technology transfer and education.

When we speak of technology transfer, we usually think of "hardware" items, that is, the use of new kinds of capital or new ways of operating existing capital. We think of changing inputs of materials or energy. And in many best practices these would be needed. There are other technology transfers that involve "software"--how the same things done now can be done differently. For example, the Chicago DC-10 crash was caused by an improper repair procedure. There are several ways in which this kind of fracture prevention can be approached. But, certainly, one of them would involve the provision of repair/operation manuals which emphasized <u>why</u> certain things should be done in only one way.

Generally speaking, best fracture control practices are good business. They save resources (which cost money) for either the producers or the users of various goods and services. Therefore, they either save the practicer money (enhancing profits) or save his customer money (enhancing good will). These best practices can be achieved through the private sector. Technical, scientific or trade associations generally provide the best avenues of action.

There were, however, in the World I - World III difference tables, many negative entries. These would imply that the adoption of best practices in regard to a single cell or sector would <u>cost</u> money, not save it, although there are overall societal gains. Where there are large societal benefits that do not accrue to the firm or sector, the government may need to provide a proper incentive for the adoption of best practice. We also note that some negative entries merely represent a tradeoff with positive entries in the sector, with or without societal benefits. Such tradeoffs represent the fact that in the adoption of any new technology or practice by any producer, there can be "winners" and "losers" among all other sectors.

Future Reducible Costs

The analysis of World IV (in Chapter VII) throw considerable light on the kinds of R&D that will have to be undertaken successfully if we are ever to attain future best practices that are significantly better than those now possible. The $23.4 billion in 1978 terms that probably can be saved by those future best practices are substantial and certainly justify the requisite effort. It must be pointed out, however, that these savings will be more costly to achieve, since they will require R&D in addition to education and technology transfer. Our present evidence indicates that there are three areas of R&D that are most promising in this regard: first, process developments that will result in higher quality and more uniform materials; second, the development of new basic materials for high-volume uses--this includes the possibility of improved characteristics that allow these new materials to substitute for those presently in use; and third, the development of better instruments and procedures for nondestructive evaluation (NDE). The judgments that lead to these conclusions take into account past trends and achievements in R&D, the kinds of R&D currently being undertaken and their likelihood of success, and the needs for better technologies that are indicated by current testing programs.

Special Sectoral Analysis

If the steps are to be taken that are capable of reducing fracture costs, they will have to be guided by information concerning the sectors associated with the several kinds of costs and the precise nature of those associations. In the Corrosion Study, a device termed the Industry Indicators was proposed for this use. Unfortunately, however, these Indicators were distorted by certain conventions necessary to operate the I/O tables, that did not actually reflect technological reality. We have attempted to improve on the Indicators by using normalized row and column relations to separate technology-driven and demand-driven sector costs. These normalized costs are described in the Addendum to Chapter VIII.

Someone will have to undertake the systematic analysis of sectoral cost relationships, if public and private efforts are to be effectively guided. There are at least two alternative paths for the accomplishment of this work: (a) The Bureau undertakes it, utilizing the results of this research program (as it did with the Corrosion Study); or (b) Battelle undertakes it in the form of an industrially sponsored study or program of studies. The data that can support such an effort--regardless of by whom--are provided by this report, and especially by the tables in Appendix H. We have tried to provide both a guide for these analyses and actual examples of the analyses and their results, especially in Chapters V, VII and VIII.

APPENDIX A. GLOSSARY

"A" Matrix: matrix of direct technical coefficients (q.v.), also called the flow matrix; the value of each coefficient indicates the (fractional) dollar's worth of inputs from the row sector necessary to produce one dollar's worth of the column sector's output.

Annual Replacement Rate: the average, annual rate at which existing capital stock (private or social) is replaced. See "'R' Matrix".

"B" Matrix: a matrix of capital-to-output coefficients; also called the capital matrix (q.v.).

Base (for determining cost of fracture): See "World II".

Capital (or Producer Capital): in the context of this study, this term refers only to physical plant and/or equipment that is not directly consumed or changed in form, but is used in the production of goods and services, either for sale or for consumption. By general usage, all items of capital have a useful life of one year or more.

Capital Matrix: a matrix of capital-to-output coefficients; also called the "B" Matrix. Each cell indicates the value of capital produced by the row sector and used by the column sector.

Capital/Output Coefficient: the value of capital equipment required by an industry in order for it to produce one dollar's worth of annual output. The coefficient is measured in terms of capital replacement value and at the using sector's full capacity.

Cell: a single value or entry in a matrix or vector. A cell is defined as the intersection of a row and column.

Consumer Capital: equipment, structures, and other durable goods owned and used by individuals for their own enjoyment.

Corrosion Study: an earlier NBS-supported project on "Economic Effects of Metallic Corrosion in the United States". This project relates directly to the present "Cost of Fracture" study in that the same general methodology was applied. Significant differences between these two projects are discussed in the text.

Depreciation: the incremental decrease in the value of capital because of wear, aging or obsolescence.

Diagonal Matrix: a matrix which contains values only in the diagonal cells, with zeros in all off-diagonal cells.

Direct Costs: the costs to an industrial sector that accrue as it purchases inputs and produces its products. See also "Indirect Costs".

Direct Technical Coefficient: a value which indicates the fractional dollar's worth of input from the row sector required to produce one dollar's worth of the column sector's output. These coefficients are the cells of the "A" matrix (q.v.).

Disaggregation: the separation of an industrial sector (in the Input/Output sense) into two or more of its component parts; the sector's row and column in each of the Input/Output model matrices are separated into two or more component rows and columns.

Dollar-Flow Table: see "Transaction Table".

Durable Goods: products which last in excess of one year and which do not change form during their use. See "Capital".

Dynamic Inverse: a transformation of a matrix containing direct technical coefficients, capital replacement requirements, and capital growth requirements $(I-A-B \circledast G-B \circledast R)^{-1}$, where "I" is the Identity matrix and the other symbols are defined in this Glossary.

Econometric Model: a mathematical representation (approximation) of an economic system.

Economic Costs: that group of social costs which can easily be expressed in dollar (money) terms because they involve the use or consumption of resources (materials, energy, labor, etc.).

Environmental Degradation Model: the supplemental model which receives environmentally relevant inputs from the Events model (q.v.) and calculates the associated costs to society. These costs can take either of two forms, the economic costs of environmental cleanup or the imputed costs of environmental degradation.

Event: any unplanned occurence -- breakdown, accident, natural catastrophe, etc. -- which does or could involve fracture and which has socially undesirable consequences.

Events Model: the supplemental model that categorizes events (q.v.) according to fracture relevance, nature of consequences and severity of impacts. According to the nature of consequences, this model feeds triggering data into the Environmental Degradation, Injury Cost and Property Loss Models. (qq.v.)

Ex ante: a process of determining past, present, or future model parameters through use of expert knowledge and opinion rather than through the manipulation of existing statistics. Literally, the Latin term means "from before."

Ex post: a process of estimating model parameters through use of historical, existing statistics. Literally, the Latin term means "from after."

Final Consumers: consist of private individuals purchasing for their own satisfaction, governments, private investors, and parties receiving U.S. exports.

Final Demand: in national income accounting terms, the consumption attributable to private investors, individuals purchasing for their own private use, governments, net inventory change, and exports.

Flow Coefficient: also called direct technical coefficient. Dollar's worth of inputs required from a given industry for some other industry to produce one dollar's worth of output.

Fracture or Fracture/Deformation: material failure through separation or change of shape that does not involve corrosion or normal wear. Failures for reasons of fracture and/or deformation include those resulting from application of loads which exceed original design and from such time-related fracture processes as creep, fatigue and embrittlement.

Future Best Fracture Control Practice: the most economically efficient use of labor, materials, energy, and technical expertise deemed possible with ultimately available fracture control technology. This would embody the level of technology toward which totally successful R&D might approach as an asymptote. Conceptually, "best practice" should be defined in terms of the total society. See "World IV" and "Present Best Fracture Control Practice".

Future Non-Reducible Cost of Fracture: that portion of the total cost of fracture that cannot be avoided by using either present or ultimate future best fracture control practices. The difference between World IV and World II (qq.v.).

Future Reducible Cost of Fracture: that portion of the total cost of fracture which could be avoided if ultimate future best fracture control practices (in contrast with present best practices) were used. The difference between World III and World IV (qq.v.).

"G" Matrix: a diagonal matrix of industrial sector growth rates.

GNP: the gross national product, that is, the value of the final output of an economy, measured without double counting.

Growth Capital: annual capital equipment purchases which may be attributed to the fact that the economy is growing.

Imputed Costs: that group of social costs which, while real, cannot be directly evaluated in money or resource terms. For example, pain is a social cost; however, imputation is required to place a dollar evaluation on it.

Indirect Costs: the costs which accrue in producing the inputs to a particular production process, and the costs of producing the inputs to the inputs until the additional costs become negligible. See also "Direct Costs."

Industry Indicator: a special index used in the Corrosion Study (q.v.) to help assign relative total costs of fracture to individual industrial sectors. This index and approach are not used in the present study, having been replaced by an analysis which considered the potential impacts of future research in a number of different areas (see World IV).

Injury Cost Model: the supplemental model which receives human injury inputs from the Events model and calculates the associated costs to society. These costs can take either of two forms: the economic costs of medical treatment and/or of lost human productive effort, or the imputed costs of pain and suffering.

Input: a necessary element in the production of a sector's output. In general, inputs consist of raw materials, energy, intermediate components, supplies, purchased services, and value added. The total value of a sector's inputs is equal to the total value of its output.

Input/Output: a particular methodology used in modeling an economic system. It consists of a set of simultaneous equations which may be solved for the system's total output.

Intermediate Consumers: those industries purchasing products which are to be transformed into different products. Compare with "Final Consumers."

Inverse: a transformation of the "A" Matrix. Each cell in the inverse indicates the total dollar's worth of inputs from the row sector necessary in order for the column sector to deliver one dollar's worth of output to its own final demand.

Inversion: the process by which a matrix is transformed into its inverse.

Matrix: a table consisting of rows and columns. In mathematics, a "short-hand" way of expressing a set of simultaneous equations.

Output: the result of the productive process; the totality of goods and services produced and sold by a sector. The value of a sector's output is equal to the total value of all its inputs.

Present Best Fracture Control Practice: the most economically efficient use of labor, materials, energy, and technical expertise possible with presently-available fracture control technology. Conceptually, "best practice" should be defined in terms of the total society. See "World III."

Presently Non-Reducible Cost of Fracture: that portion of the total cost of fracture which cannot be reduced by application of best current fracture control practice. The difference between World III and World II (qq.v.).

Presently Reducible Cost of Fracture: that portion of the total costs of fracture which could be avoided if best fracture control practices were used. The difference between World I and World III (qq.v.).

Primary Products: in terms of the Standard Industrial Commodity Code (SIC), primary products are those products in terms of which an industry is defined. For example, milk is a primary product of the dairy industry; if produced outside the dairy industry, milk will be termed "secondary" to that other industry.

Private Fixed Capital Formation: the annual purchase of physical capital (plant and equipment) by private investors for reasons of growth and replacement.

Process Sectors: industrial sectors of the Input/Output model which use one technological process to produce a homogeneous product (or group of products).

Producer Capital: See "Capital".

Property Loss Model: the supplemental model which receives property loss or destruction inputs from the Events model and calculates the associated costs to society. These costs can take either of two forms: either the economic costs of the destroyed property or the imputed costs of business delays.

"R" Matrix: a matrix of annual average capital replacement rates; each cell indicates the average annual replacement of capital produced by the row sector and used by the column sector.

Replacement Capital: annual capital purchases which are made to replace obsolete, worn-out, or broken plant and equipment.

Replacement Life: the time in years to first replacement of a piece of capital equipment.

Row Rules: a set of technology-based or practice-based generalizations that may be applied across all columns of a given matrix (e.g., "A", "B", etc.), and which reflect input changes characteristic of each World. Selected column-specific deviations from the Row Rules are made to account for special exceptions or applications.

Sector: an industry, part of an industry, or group of industries that is treated as a productive unit in an Input/Output table. Within the context of this study, a sector is defined as the process or group of processes which produces primary products (q.v.) only.

Social Capital: equipment, structures and other durable goods that are owned by public (governmental) agencies and used for the general benefit of society.

Social Savings: an accounting mechanism in the modified Input/Output model used in this study. The social savings account for real resources being consumed and value added accruing because fracture occurs.

Stipulated Final Demand: the value of goods and services which accrue to individuals, government, net inventory change, and exports.

Stock Coefficient: also called capital coefficient; indicates the value of capital stock of a certain type required for an industry to produce an additional dollar of its output.

Supplemental Models: in the context of this study, four separate submodels that permit estimation of the costs to society of several important categories of "events" that are either caused or complicated by fracture. See also "Events Model", "Environmental Degradation Model", "Injury Cost Model", and "Property Loss Model".

Total Cost of Fracture: the total resources consumed in our economy because of the fact that fracture occurs. The difference between World I and World II (q.v.).

Total Output: the value of the total goods or services produced by some industrial sector.

Transaction Table: the usual form in which an Input/Output table is expressed; also called the "Dollar-Flow Table" (q.v.). In it, each cell displays the total dollar value of the products, services, etc., that the row-sector sells to the column-sector or to the column-element of final demand. Conventionally, all these dollar values are expressed in producer-prices.

"U" Matrix: a matrix in which the useful life is indicated for each capital item. This matrix has an entry for every non-zero entry in the "B" Matrix. Useful lives are entered as a range of discrete years and indicate the life of that capital before it must be replaced for reasons of breakdown, wear, or technological obsolescence.

Useful Lives: in the context of this study, the span of years over which durable goods of all sorts can be expected to be used before being scrapped or discarded. The useful life of a durable item is ended by major failure (beyond economic repair), by wear, or by obsolescence. See also "Replacement Life."

Value Added: the additional value accruing to a sector's inputs as they are fashioned into the product itself; included are wages, salaries, rents, profits, interest, taxes, and depreciation. It can also be defined as the value of the productive factors contributed by the industry itself, rather than purchased from other industries.

Vector: a single row or column of values.

World I: the present environment and economy as they now exist.

World II: a hypothetical environment and economy in which no fracture occurs.

World III: a hypothetical economy in which present best fracture control practices exist and are universally applied.

World IV: a hypothetical economy in which future best fracture control practices exist and are universally applied. Note that for purposes of this study, World IV is never established in Input/Output table form.

APPENDIX B. THE INPUT/OUTPUT MODEL

Input/Output modeling of an economy permits an accounting of the many and varied transactions which occur in that economy during a typical year. Through a detailed description of interindustry sales and purchases, the I/O approach considers all the transactions required for intermediate inputs to productive processes, as well as for the replacement, expansion, or maintenance of capital equipment. And finally, the model describes all the other final demands that must be satisfied by the productive sectors, along with the flows of resources which pay for labor, taxes, interest, depreciation, and profits.

General Framework

The Input/Output (I/O) model, as it will be used in this study, can be separated into two basic components:

- the direct technical coefficient matrix (A matrix)
- the capital module (B, G, and R matrices).

The relationship which ties both components together is

$$X = AX + B \circledast GX + B \circledast RX + \overline{FD} \qquad \text{(B-1)}$$

where

X is a vector of total output
A is a matrix of direct technical coefficients
B is a matrix of capital/output coefficients
G is a full matrix of industry growth rates, with each entry in any column being equal to the growth rate of that column sector
R is a matrix of capital replacement rates
$\overline{FD}$ is stipulated final demand (personal consumption expenditures, exports, and inventory change; excludes capital), and $\circledast$ is the symbol for the Kroenecker matrix operator.

Equation (B-1) states that an industry's total output is distributed among intermediate consumers, purchasers of capital (for both growth and replacement), and final consumers. The term AX is the output consumed by intermediate users, $B \circledast GX$ is the output which is allocated to growth capital, $B \circledast RX$ is the output allocated to replacement of worn out capital, and $\overline{FD}$ is the output accruing to final consumers. Equation (B-1) may be solved for total output, X, by the following:

$$X = [I - A - B \circledast (G + R)]^{-1} * \overline{FD} \qquad \text{(B-2)}$$

where $[I - A - B \circledast (G + R)]^{-1}$ is an inverse matrix.

Equation (B-2), often termed the dynamic inverse, is key to the I/O formulation used in this study. It treats the capital stock coefficients $B \circledast G$ and $B \circledast R$ as if they were flow coefficients and combines them with the direct technical coefficients, allowing capital purchases to be a function of stipulated final demand. The resulting inversion permits the specification of the output required from each sector, both directly and indirectly, to support the production of one unit amont of final demand for the products of another sector.

Model Assumptions

Assumptions implicit to the I/O model used in this study include:

- linearity assumption: an industry's inputs are proportional to its outputs, i.e., requirements are not related to firm size, volume of output, etc.
- homogenous product assumption: each I/O sector produces a slowly changing, average bundle of products (assumes away rapidly changing product mixes with diverse production technologies).
- inelasticity assumption: eliminates cross elasticities of substitutions among input requirements.
- steady growth assumption: stipulates that all sectors have been growing at their long term rate of growth.
- average technology assumption: implies that each industry's production function can be represented by average 1978 technology for the sector in which it is included.
- full employment assumption: corrects the base, real-year 1978 I/O table to "full employment" output levels, i.e., final demands and outputs become slightly higher than actually was the case in 1978 so as to represent the full potential capacity of the national economy (and thus the full costs of fracture).
- import transferability assumption: assumes that foreign imports of directly substatutable products are treated as being purchased as inputs by the column sectors that would have produced them; all such imports are carried outside the intermediate and inverse matrices so as to maintain the technological integrity of input coefficient relationships.

We have also used the technique of defining a Social Savings/Social Cost subvector of Value Added. This accounts for reductions in GNP that would result from less or no fracture, and accumulates (outside the A matrix) materials and labor resources which otherwise would have been employed toward eliminating or reducing fracture. The resultant savings can be assumed to be directed toward other unidentified purposes in the national economy.

The A Matrix

The A matrix, or matrix of interindustry transactions, shows the amounts of purchases and sales between and among different producing sectors of the economy. These transactions involve primary and intermediate goods and services, accounting for all required inputs to each respective productive process. Each sector is shown, on the one hand, as selling parts of its outputs to other producing sectors and, on the other, as buying from other producing sectors the inputs that it needs.

Listed as rows, the productive sectors of the economy represent sources of supply. Reading across a given sector's row details the sales which that sector makes in distributing its output. These same sectors, listed as column headings, represent markets. Thus, reading down any single column indicates the sources from which that particular sector purchases its inputs--that is, the supplies, raw materials, power, etc.--which it then combines with its own contributions to create its group of products. Therefore, any given cell (i.e. the intersection of a given row with a given column) shows what the industry defining the row sold to the industry defining the column; or vice versa, it shows what the industry defining the column purchased from the industry defining the row.

After dividing each column entry by its total value, each cell value (direct technical coefficient) is expressed in terms of proportions. Thus, each column sum of the A matrix plus the sum of Value Added (plus imports and social savings) is equal to one. Similarly, the sum of the column coefficients in the A matrix is equal to the column sector's use of domestic intermediate inputs per dollar of its own output and comparable imports.

The General Concept of the Capital Module

Private fixed capital formation (PFCF) is one of the subvectors of final demand in the I/O model, representing the demand from the entire economy for the equipment, machinery and structures used in all productive processes as well as the structures resided in by consumers.

The formation of new plant-and-equipment capital by industry can be thought of as triggered by need for growth, by need for replacement (due to obsolescence or degradation), or by government requirements (e.g., for environmental protection). Growth refers primarily to the growth of demand for an industry's output, regardless of whether the demand is final or intermediate, foreign or domestic. Replacement refers to both replacements due to technological change and replacements which result from the age structure of existing capital. Additional capital changes result from governmental regulations which, for the study, will be estimated with reference to policy directives and added to our modular estimates.

In order to estimate the amounts of new capital which each capital-using sector will purchase from each capital-producing sector during a given year, the following matrices are manipulated:

- The stipulated (noncapital) final demands which each sector must satisfy ($\overline{FD}$)
- The matrix of capital coefficients (B)
- The capacity growth rate matrix (G)
- The capital replacement rate matrix (R)
- The matrix of direct technical coefficients

Each of these is discussed generally below.

The B-Matrix. Generally, the capital matrix shows how much capital the column sector (capital-user) will purchase from each row sector (capital-producer) in order to create new capacity to produce one dollar's worth of output per year. It is expressed in 1978 dollars and price relationships.

The B-Matrix used in this study is a current best-practice (as of 1979-80), balanced-expansion, stock matrix in 150 sector detail which assumes optimal engineering requirements but no excess capacities. Thus, to increase an industry's output by one percent, every capital input must increase by one percent. This means that when the associated capital/output ratios are used to convert total outputs to total capital already in place, it is implicitly assumed that all plant and equipment is optimal from an engineering point of view. Another way of stating this is that capacity is expressed in terms of its current replacement value.

The Growth Matrix. The growth matrix is a diagonal matrix which determines how much new capacity must be formed in the economy to keep up with its long term demands. Each sector's rate of growth is approximated in terms of the direct plus indirect growths of general demand based on total output. In the actual program, total output is taken from Battelle's full employment trend tables.

The Replacement and Useful Life Matrices. Since we have no precise vintage composition of total capital, we assume that the age-structure of each capital-using industry's existent stock of capital results from its steady growth rate (g). Replacement rates would therefore be a function of the growth rate and the replacement life of that stock. We have used the Internal Revenue Service's Bulletin F as our source of the replacement life expectancies of each sector's plant and equipment.

The replacement rate (r) for each sector is taken as a joint function of both replacement life expectancy and sector growth. The R matrix is a full matrix, like the B matrix. It is derived in turn from a corresponding matrix of replacement lives (U) by the following procedure.

Working from entries of depreciation life Bulletin F, every cell U_{ij} corresponding with a nonzero cell in B is assigned a replacement life expectancy value. The assigned value may take the form of a given number of years or of a range of years. Average annual growth rates for each column sector are then derived and used to describe the entire cycle of replacement lives.

In actually setting up the replacement matrix, R, we establish a value of r_{ij} for each corresponding value of u_{ij}. If a given cell has a single replacement life (e.g., 5 years) there will be only a single replacement rate. However, if a particular cell is shown as having a range of replacement lives (e.g., 5-10 years) there will be a range of replacement rates (one for 5 years, one for 6 years, and so on); and the corresponding single value entered in the R-matrix will be the simple mean of these replacement rates.

Final Demands. Final demands account for the third major component of the Input-Output model. They represent the final disposition of goods and services produced by the economy.

Specifically, the stipulated final demands used in this study may be separated into expenditures for:

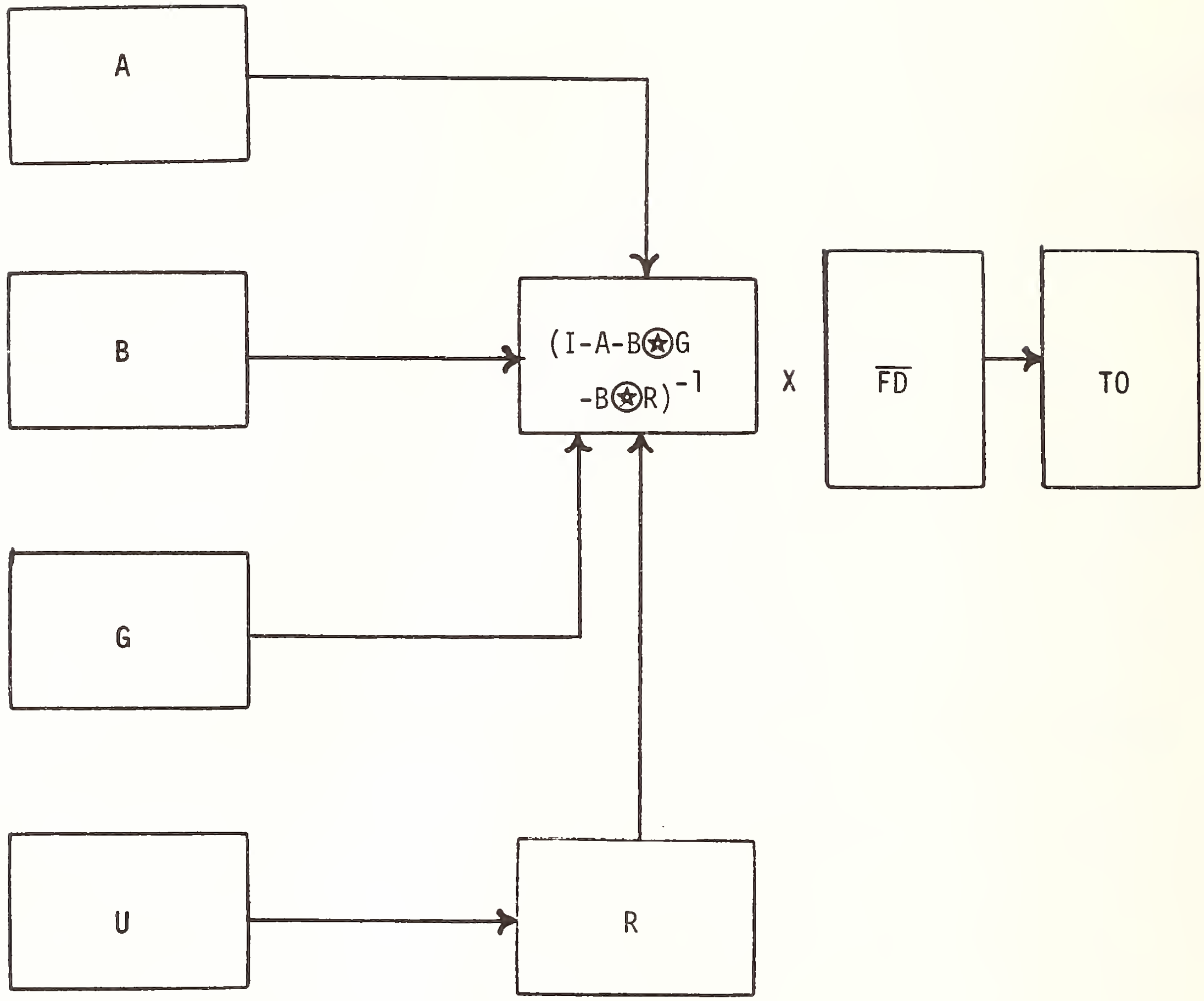
- Personal Consumption
- Government (Federal, state, local) purchases
- Exports
- Net inventory change.

Normally, the sum of the final demands is equivalent to GNP. In this study, however, the stipulated final demands must be adjusted in order to achieve a sum equivalent to GNP. The adjustments include adding gross private domestic investment to, and subtracting imports from, the sum of the above categories.

The Final Capital Matrices. After total outputs (X) have been computed via the dynamic inverse and the stipulated final demand, the detailed capital transactions matrices are computed from the following relationship, which is graphically presented in Figure B-1.

$$X = [I - (A + B \circledast (G + R))]^{-1} * FD$$

In this form, given the long term growth rates (G) mentioned above, the equation permits the computation of total output.



A = Direct Technical Coefficients

B = Capital Coefficients

G = Diagonal of Growth Rates

U = Useful Lives (ranges in whole years)

R = Replacement Rates

$(I-A-B\circledast G-B\circledast R)^{-1}$ = Modified Dynamic Inverse

$\overline{FD}$ = Noncapital Final Demands

TO = Total Output

FIGURE B-1. MATRIX FLOW OF INPUT/OUTPUT MODEL

In matrix form, these tables provide capital market data that show how much capital goods must be purchases by each capital-using sector from each capital-producing sector, if the capacity of the economy is to satisfy all final demands.

The column of row sums of the total capital matrix enters the Capital Formation column in the final demand vector of the I/O transactions table. When the total capital matrix is added, cell-by-cell, to the intermediate and other final transactions matrix of the I/O table, this provides us with a complete market profile for every row sector, regardless of the nature of its output.

Details of the various matrices derived in this study are presented in Appendix (H).

Special Features

There are two most important features that merit special attention. First, the Battelle I/O Model approach is based upon the technologies of production. Changes in such technologies are reflected in terms of changes in the purchases by one sector from another. Second, it can be readily seen from Equation (B-2) that a change in any element of the matrices A, B, G, or R will have an impact--however small--on each of the elements of vector X. Thus, any single factor which affects the technology of production in any sector will filter its way throughout the economy.

Sectoral Format

The standard format of the Battelle Input/Output Model divides the productive economy into 126 productive sectors and six final demand subcategories. This format is, however, readily altered by the aggregation or disaggregation of specific sectors to provide the kinds and degrees of detail most useful in dealing with particular problems. For the present study of the costs of material failures (fractures and deformations) in the United States, the sectoral format has been modified to consist of 150 productive sectors and eight subcategories of final demand. These elements are set forth and defined in Appendix C.

APPENDIX C. I/O SECTORS: SIC's, DEFINITIONS AND NOTES

1.01 Livestock and Livestock Products

Includes agricultural processes involved in raising, feeding, and selling livestock -- defined as animals and animal specialties, such as cattle, poultry, fish, and fur bearing animals, and bees -- and/or in extracting their products (milk, eggs, fur, honey). Also includes selected services, such as breeding, milk testing, etc.

Related SIC's: 02, parts of 01 (especially in 0191) and parts of 07 (See 1.04, below).

1.02 Field and Orchard Crops

Includes agricultural processes involved in raising, harvesting field and orchard crops, including flowers, mushrooms, sod, and plants. Also includes farm management, soil preparation services, and farm labor contractors.

Related SIC's: 01, parts of 02 (especially in 0291) and parts of 07 (See 1.04, below).

1A03 Forestry Products

Includes processes involved in forestry operations (but not lumbering) but does include the collection of forest products such as gums, barks, spanish moss, saps, etc.

Related SIC's: 08, except 085

1B03 Fishing, Hunting and Trapping

Includes processes involved in commercial marine and fresh water fishing and fish hatcheries (but not fish farms). Also includes commercial hunting and trapping, the operation of fish and game preserves, and wild life management.

Related SIC's: 09

1.04 Services to Agriculture, Forestry and Fishery

Includes all services to the above processes, except those providing commercial activities integral to them. E.g., commercial harvesting is included with 1.02, above, but operations to prepare harvested crops for market are included in 1.04.

Related SIC's: parts of 07, especially 0723, 0724, 074, 075, 078

2.01 Iron and Ferroalloys Ores Mining

Includes processes of mining, milling and beneficiating iron and ferroalloy ores.

Related SIC's: 101, 106, parts of 108

2X02 Nonferrous Ores Mining

Includes processes of mining, milling and beneficiating all nonferrous ores.

Related SIC's: 102-105, 109, parts of 108

2A04 Underground Coal Mining

Includes processes of mining, breaking, and cleaning coal from shaft mines.

Related SIC's: parts of 11 and 12

2B04 Strip Coal Mining

Includes processes of mining, breaking and cleaning coal from surface (open pit) mines. Includes removal and replacement of overburden and restoration of land surface.

Related SIC's: parts of 11 and 12

2C04 Other Coal Mining

Includes processes of auger and contour mining of coal, plus breaking and cleaning.

Related SIC's: parts of 11 and 12

2A05 Crude Petroleum

Includes processes involved in locating and extracting crude petroleum from wells or from oil sands and shales. Includes all contract services provided up to the point of shipment from the producing property; does not include pipeline transportation or refining.

Although this sector includes extraction from oil shale and oil sands, by definition, coefficients in column 2A05 do not yet reflect such technologies.

Related SIC's: part of 13

2B05 Natural Gas

Includes processes involved in locating and extracting natural gas (including natural gas liquids) from wells. Includes gathering lines, but not pipelines; includes condensation, but not fractionating or refining, of natural gas liquids.

Related SIC's: part of 13

2.06 Stone and Clay Mining

Includes processes of mining/quarrying, milling and otherwise preparing for further use all nonfuel, nonmetallic minerals, except chemical and fertilizer minerals.

Related SIC's: 141-145, 149 and related parts of 148

2.07 Chemicals and Fertilizer Minerals Mining

Includes processes of mining/quarrying, milling and otherwise preparing for future use all nonfuel, nonmetallic chemical and fertilizer minerals.

Related SIC's: 147 and related parts of 148

3A01 Beverages

Includes processes of producing beverages for human consumption, including malt beverages, wines, liquors, soft-drinks, and flavoring extracts, and their containerization into pressure-resistant vessels of glass, plastic and/or metal.

Related SIC's: 208

3B01 All Other Food and Kindred Products

Includes processes involved in the manufacture, and containerization of all food products, except beverages. Also includes preparation of animal feeds.

Related SIC's: 20, except 208

3.02 Tobacco Manufacturers

Includes processes of preparing tobacco for use in manufactures (including stemming and redrying) and producing cigarettes, cigars, chewing and smoking tobacco, and snuff.

Related SIC's: 21

3X03 Leather and Leather Products

Includes all processes involved in the tanning of hides and skins and the production of leather products for industrial or consumer use. Includes footwear and luggage. Capital items include protective shoes, luggage.

Related SIC's: 31

3X05 Fabrics, Yarns, Threads, and Soft Floor Coverings

Includes all processes related to producing fabrics for the needle trades and yarns and threads for input into all textile products. Primarily involves spinning, weaving, dyeing and finishing of natural and manmade fibers. Also includes all processes involved in weaving rugs and carpets from yarns, and in braiding and hooking rugs and mats from a variety of materials.

Related SIC's: 221-4, 226, 227, 228

3A07 Metal Tire Cord

Includes all processes invloved in producing metal cords and fabric for reinforcing tires and flexible belting. Does not include the metal cable in tire beading (See 8.07).

Related SIC's: part of 2296

3B07 Other Tire Cord and Miscellaneous Textile Goods

Includes all processes involved in producing nonmetallic tire cords and fabrics, plus a variety of miscellaneous other textile products such as felts and other non-woven fabrics, laces, coated fabrics, wastes, cordage and twine, nets, etc.

Related SIC's: 229, excluding part of 2296

3X08 Apparel and Miscellaneous Fabricated Textile Products

Includes all processes involved in the needle trades, knitting, and machine embroidery.

Related SIC's: 225 and 23

4.01 Sawmills and Planning Mills

Includes all processes involved in converting logs into dimensional lumber.

Related SIC's: 242

4.02 Veneer, Plywood, and Laminated Wood

Includes all processes involved in converting logs into veneers and/or plywood. Also includes manufacture of hardboard, chipboard, and laminated wood products.

Related SIC's: 2435, 2436, 2439, and part of 2499

4.03 All Other Lumber and Wood Products, except Containers

Includes timber cutting and the processes of producing a variety of milled, treated and other wooden products, except containers.

Related SIC's: 241, 2431, 2434, 245, and 249, except part of 2499

4.04 Wooden Containers

Includes all processes involved in producing wooden boxes, barrels, pallets, and other containers.

Related SIC's: 244

4XA5 Wooden Furniture and Fixtures

Includes all processes of producing household, office, and business furniture and fixtures with wood and the primary structural material.

Related SIC's: 2511, 2512, part of 2515, 2517, most of 2519, 2521, part of 253, 2541, and part of 259

4XB5 Metal Furniture and Fixtures

Includes all processes of producing household, office and business furniture and fixtures with metal as the primary structural material.

Related SIC's: 2514, part of 2515, part of 2519, 2522, part of 253, 2542, and part of 259

4.07 Pulp, Paper, and Paper Products, except Containers

Includes all processes in making and converting paper, except the manufacture of paperboard containers. Includes paper building products.

Related SIC's: 261, 262, 263, 264, 266

4.08 Paperboard Containers and Boxes

Includes all processes in the manufacture of containers and boxes from paperboard and fiberboard, including vulcanized fiber.

Related SIC's: 265

5.01 Petroleum Refining and Related Products

Includes all processes of petroleum refining to produce gasoline, kerosene, distillate and residual fuel oils, lubricants and other crude petroleum derivative products.

Related SIC's: 291, part of 299

5.02 Paving Mixtures and Asphalt Products

Includes all processes of producing paving and roofing materials from asphalt and petroleum derivatives.

Related SIC's: 295

5.03 Industrial Inorganic and Organic Chemicals

Includes all processes of producing basic chemicals such as acids, alkalies, salts, dyes, solvents, and plasticizers.

Related SIC's: 281, 2865, 2869

5X04 Agricultural Chemicals

Includes all processes of producing nitrogenous and phosphatic fertilizers and formulating and preparing herbicides, pesticides and other agricultural chemicals.

Related SIC's: 287

5A06 Adhesives

Includes processes related to the manufacture of industrial and household adhesives, glues, caulking and sealing compounds, and synthetic cements.

Related SIC's: 2891

5B06 All Other Chemical Products

Includes processes involved in producing natural gum and wood chemicals, explosives, printing and writing ink, heat insulating compounds, corrosion preventive lubricants.

Related SIC's: 2861, 289 (except 2891)

5.09 Drugs

Includes all processes involved in the manufacture of medicinal chemicals and pharmaceutical products, including blood derivatives for human use and the milling of botanicals.

Related SIC's: 283

5X10 Cleaning and Toilet Preparations

Includes processes related to the manufacture of soaps, detergents, cleaning and polishing preparations, natural and synthetic perfumes, cosmetics, and other toilet preparations.

Related SIC's: 284

5.12 Paints and Allied Products

Includes processes of manufacturing paints, varnishes, lacquers, enamels; woodfillers and sealers; paint and varnish removers and cleaners and other allied paint products.

Related SIC's: 285

P.07 Plastics Materials, Resins, and Synthetic Rubber

Includes processes involved in the manufacture of both cellulosic and noncellulosic plastic materials and resins, and synthetic rubber (vulcanizable elastomers). Does not include processes of molding and fabricating plastics into shapes and finished products.

Related SIC's: 2821, 2822

P.08 Organic Manmade Fibers

Includes processes related to the manufacture of cellulosic and synthetic organic fibers in the form of monofilament, yarn, staple or tow suitable for further manufacture on textile processing equipment.

Related SIC's: 2823, 2824

P.13 Tires and Inner Tubes

Includes all processes of making solid and cushion tires, pneumatic casings, inner tubes, and repair and retreading materials for all types of vehicles.

Related SIC's: 301

PA14 Industrial Rubber Belts

Includes processes involved in the manufacture of rubber industrial belting (conveyor, elevator, transmission, etc). Also includes synthetic rubber (neoprene) V-belts, which are often misclassified as plastic belts.

Related SIC's: part of 3041

PB14 All Other Rubber Products

Includes processes associated with the manufacture of rubber footwear and repair materials (e.g., heels), rubber outerwear, hoses, floor tile, life rafts, baby pants and other miscellaneous rubber specialties and sundries.

Related SIC's: 3021, 3021, part of 3041, part of 3069

PA15 Plastic Pipe

Includes processes associated with the manufacture of all types of plastic pipe and fittings. Includes plastic irrigation systems.

Related SIC's: part of 3079

PB15 Plastic Containers

Includes all processes related to the manufacture of plastic containers except bags. Includes bottles, jars, boxes, drums, and tanks.

Related SIC's: part of 3079

PC15 All other Manufactured Plastic Products

Includes processes related to the molding of primary plastics into sheets, rods, and monofilaments and their fabrication into miscellaneous finished plastics products, including kitchenware and tableware, hardware and fittings, insulating and cushioning materials, siding and gutters, plastic bags and tubing, among others.

Related SIC's: part of 307

6A01 Flat Glass

Includes all processes of producing flat glass, including structural, insulating, plate, sheet, window, and laminated glass.

Related SIC's: 3211, part of 3231

6B01 Glass Containers

Includes all processes pf producing glass containers for commercial packing and bottling, and for home canning.

Related SIC's: 3221, part of 3229, part of 3231

6C01 Automobile and Truck Windshields

Includes processes associated with the manufacture of safety, tempered, and laminated glass for motor vehicle windshields.

Related SIC's: part of 3231

6D01 All Other Glass Products

Includes processes related to shaping, blowing and pressing of glass into a variety of finished (mirrors, vases, drinking vessels, cookware) and intermediate products (TV tube blanks, lighting glassware, lens blanks). Does not include optical and ophthalmic lenses, which are in 14.04.

Related SIC's: part of 3229, part of 3231

6.02 Hydraulic Cement, Lime and Gypsum Products

Includes all processes of producing hydraulic cement, lime, and products composed wholly or chiefly of gypsum, including plaster and plasterboard.

Related SIC's: 324, 3274-5

6A03 Structural Clay Products, except Clay Refractories

Includes processes of producing brick and structural clay products including ceramic wall and floor tile and clay sewer pipe.

Related SIC's: 3251, 3253, part of 3259

6B03 Structural Concrete Products and Ready-mixed Concrete

Includes all processes of producing concrete building blocks, bricks, products composed of a combination of cement and aggregate (with or without metal reinforcings) and the mixing and delivery of ready-mixed concrete.

Related SIC's: 3271-3273

6C03 Pottery, Whiteware and Porcelain Products

Includes processes related to the manufacture of chinaware, earthenware, plumbing fixtures and bathroom accessories, and molded porcelain parts for electrical devices, such as insulators and spark plug parts.

Related SIC's: 326

6D03 Clay and Nonclay Refractories

Includes processes of producing clay firebrick and other heat resisting clay products, plus refractories and crucibles made from materials other than clay, including graphite refractories.

Important to note:

1. We have treated the main sources of fracture for these products as being (a) breakage in delivery
   (b) heat cycling in use.

2. Most 6D03 failures, however, result from corrosion.

3. There are two main types of using sectors:

   (a) Those which manufacture capital equipment in which refractories are components.

   (b) Those which operate such capital and purchase refractories as replacements.

4. Note that, for refractories, the replacement purchases come from 6D03 and not from the section providing the capital into which they go.

Related SIC's: 3255, part of 3259, 3297

6A04 Abrasives, Including Grinding Wheels

Includes all processes of producing natural or synthetic abrasive products, including grinding wheels, sand paper, steel wool, and buffing and polishing wheels.

Related SIC's: 3291

6B04 All Other Stone and Nonmetallic Mineral Products

Includes processes of cutting, crushing, grinding or otherwise preparing of all other stone, clay or ceramic minerals, producing asbestos products and sealing devices, and all processes of producing mineral and glass insulation wool.

Related SIC's: 3281, 3292, 3293-3296, 3299

7A01 Iron and Carbon Steel

Includes processes of smelting and refining carbon steels and the production of basic shapes. Includes the production of pig iron, coke, forgings and castings. The specialized production of ferroalloy additives has been assigned to this sector.

Since rolling mills are included with the primary metal activity, rails are treated here as a basic shape and are produced only in 7A01.

7B01 Alloy Steel

Includes processes of producing alloy steels (excluding stainless steel), tool steels, and basic shapes. Includes forgings and castings.

7C01 Stainless Steel

Includes processes of producing stainless steel and basic shapes, including forgings and castings.

7.03 Aluminum

Includes the processes of smelting and refining aluminum and its alloys, and basic shapes, forgings and castings.

7X04 All Other Nonferrous Metals

Includes the processes of smelting and refining all nonferrous metals except aluminum, and producing their basic shapes, forgings and castings.

8.01 Metal Cans

Includes all processes of producing cans and other metal food containers.

Related SIC's: 3411

8.02 Metal Barrels, Drums and Pails

Includes processes of producing ferrous and nonferrous shipping barrels, drums, pails and other container forms.

Related SIC's: 3412

8.03 Metal Sanitary Ware and Plumbing Fittings

Includes processes of producing enameled iron and metal sanitary ware, plumbing fixture fittings and trim, including plumber's brass goods.

Related SIC's: 3431, 3432

8.04 Nonelectric Heating Equipment

Includes processes of fabricating nonelectric heating equipment including gas, oil and coal fired equipment for the automatic utilization of these fuels.

Related SIC's: 3433

8A05 Structural Metal

Includes processes of fabricating iron and steel or other metal for structural purposes such as bridges, buildings and sections for ships, boats and barges (but not the completed structures or vessels).

Related SIC's: 3441

8B05 Boiler Shop Products

Includes processes of cutting, forming and joining metal plates, bars, sheets, pipes and other mill products for producing boilers, pressure and nonpressure tanks, weldments and other similar products.

Related SIC's: 3443

8C05 All Other Fabricated Stuctural Products

Includes process of producing structural metal products and components for buildings such as metal doors and sashes, sheet metal work, architectural metal work and prefabricated metal buildings. Also includes stove pipes, light tanks, and steel concrete reinforcing bars.

Related SIC's: 3442, 3444-344'

8.06 Screw Machine Products and Stampi..

Includes processes of producing screw machine products, bolts, nuts, washers and special industrial fasteners. Also includes such metal stampings as kitchen utensils, metal boxes, metal curtain walls, etc.

Related SIC's: 345, 346

8.07 Other Fabricated Metal Products

Includes all processes of producing cutlery, hand tools, general hardware and miscellaneous fabricated metal products, (wire, pipe fittings, springs, and metal foil), plus electroplating, polishing and coating, and plating.

Related SIC's: 342, 347, 349

9.01 Engines and Turbines

Includes processes of producing steam, gas, and hydraulic turbines, including those for complete turbine generator set units; plus internal combustion engines, not elsewhere classified, except commercial and military aircraft engines. Does not include motors in household appliances.

Related SIC's: 351

9.02 General Industrial Machinery and Equipment

Includes all processes of producing machinery, equipment and components for general industrial use, including pumps, ball bearings, compressors, blowers and fans, furnaces and ovens*, gears and other power transmission equipment, and industrial furnaces and ovens*.

* "Off-the-shelf" items

Related SIC's: 356

9.03 Machine Shop Products

Includes all processes of producing carburetors, pistons, valves and machinery and parts not elsewhere classified, such as amusement park equipment and fluid power cylinders.

Related SIC's: 359

10.01 Farm Machinery

Includes processes of producing machinery and associated equipment for all farm, garden and lawn uses. Does not include hand tools (See 8.07).

Related SIC's: 352

10.02 Construction Machinery

Includes processes of producing heavy machinery and equipment primarily used by the construction industries such as bulldozers, cranes, and excavators. All standard earthmovers are produced here.

Related SIC's: 3531

10.03 Mining Machinery

Includes all processes of producing heavy machinery and equipment used primarily by the mining industry such as drilling equipment, crushers, mining cars, and loading machines. Walking cranes, draglines and excavators (custom built for open pit mining) come from this sector.

Related SIC's: 3532

10.04 Oil Field Machinery

Includes all processes of producing machinery and equipment for use in oil and gas fields as well as for drilling water wells.

Related SIC's: 3533

10.05 Materials Handling Machinery, Except Trucks

Includes processes of manufacturing materials handling machinery and equipment such as elevators (including passenger), conveyors, and industrial hoists and cranes.

Related SIC's: 3534, 3535, 3536

10.06 Industrial Trucks and Tractors

Includes processes of manufacturing industrial trucks, tractors, trailers, stackers, and related equipment used for handling materials on floors and paved surfaces in and around industrial and commercial plants.

Related SIC's: 3537

10.07 Metalworking Machinery (including cutting tools)

Includes all processes of manufacturing metalworking machinery such as metal cutting and forming machine tools, power driven hand tools, rolling mill equipment and machinery, and welding equipment.

Related SIC's: 354

10.08 Special Industry Machinery

Includes all processes of manufacturing machinery and parts and attachments for such machinery for use by the food products, textile, woodworking, paper, printing, rubber, petroleum refining, and metal smelting industries, among others.

Related SIC's: 355

11.01 Motor Vehicles and Parts

Includes processes related to the manufacture of auto, truck, and bus bodies, all motor vehicle parts and accessories other than tires, motors, batteries, etc., and their assemblage into complete passenger automobiles, trucks, trailers, and buses.

Related SIC's: 371

11.02 Aircraft and Parts

Includes all processes related to the production of aircraft parts, auxiliary equipment including engines, and their assembly into complete aircraft. Also included are guided missile and space vehicle propulsion units and their related parts and auxiliary equipment.

Related SIC's: 372, part of 376

11.03 Ship and Boat Building and Repair

Includes processes of building and repairing all types of ships, barges, lighters, and boats.

Related SIC's: 373

11.04 Locomotives, Railcars and Rapid Transit Cars

Includes all processes of building and rebuilding locomotive and railroad, street and rapid transit cars and their associated equipment.

Related SIC's: 374

11.05 Motorcycles, Bicycles, Trailer Coaches, etc.

Includes all processes of producing motorcycles, bicycles, travel trailers, mobile homes, and similar equipment and parts. Also includes other transportation equipment such as snowmobiles, military tanks, and all-terrain vehicles.

Related SIC's: 375, 379, 2451

12.01 Electrical Measuring Instruments

Includes processes of manufacturing instruments for measuring and testing the characteristics of electricity (such as voltmeters, ammeters) and equipment for the testing of circuitry.

Related SIC's: part of 3825

12A02 Electric Generators for Power Plants

Includes all processes of producing large electric power generators and their components, for power plants.

Related SIC's: part of 3621

12B02 All Other Electric Motors and Generators

Includes all processes of producing electric motors and power generators and control equipment, including their components, for nonpower plant use.

Related SIC's: part of 3621

12.03 Industrial Controls, Transformers, etc.

Includes all processes of producing electric power transmission and distribution equipment, including power switching equipment, circuit breakers, metering panels, transformers and fuses. Also includes electric welding equipment.

Related SIC's: 361, 362 (excluding 3621)

12.04 Electric Lamps

Includes all processes of producing electric bulbs, tubes, and related light sources.

Related SIC's: 3641

12.05 Lighting Fixtures and Wiring Devices

Includes processes of producing all wiring devices including insulators (except glass and porcelain) and lighting fixtures for all residential, commercial and vehicular uses.

Related SIC's: 364 (except 3641)

12.06 Electronic Components and Accessories

Includes all processes of producing electron tubes, semiconductors, resistors, connectors, electronic capacitors, indicators, and other electronic components. Also includes antennae, styli, blank recording tapes, etc.

Related SIC's: 367

12A07 X-Ray Equipment

Includes all processes of producing radiographic, fluoroscopic, and therapeutic X-ray apparatus and tubes for all applications; excludes X-ray films and plates (which are in 14.05).

Related SIC's: 3693

12B07 All Other Miscellaneous Electrical Machinery

Includes processes of manufacturing miscellaneous electrical machinery, equipment, and supplies, including batteries, spark plugs, starting motors, generators, and alternators for cars and aircraft, extension cords and electric light bulb parts.

Related SIC's: 369 (except 3693)

13.01 Service Industry Machinery

Includes all processes of manufacturing refrigeration and service industry machinery including commercial, residential, and industrial conditioning and warm air heating equipment, and commercial laundry, dry cleaning and cooking equipment.

Related SIC's: 358

13.02 Household Appliances

Includes processes of manufacturing household appliances such as, gas ranges, household refrigerators and laundry equipment, vacuum cleaners, fans, and other appliances such as dishwashers, space heaters, hot plates and sewing machines.

Related SIC's: 363

13.03 Radio, T.V. and Communication Equipment

Includes processes of producing radio and TV receiving equipment, including phonograph records and tapes. Also includes communication equipment such as telephone and telegraph apparatus and signaling and detection equipment and apparatus.

Related SIC's: 365, 366

14A01 Fracture Control Instruments

Includes all processes of manufacturing instruments for measuring stresses and for testing and analyzing fracture processes.

Related SIC's: part of 382

14B01 All Other Scientific Instruments, Measures and Controls

Includes processes of manufacturing professional and scientific instruments and related equipment, including gyroscopes, laboratory equipment, temperature and pressure controls, counting devices, and surveying and drafting instruments.

Related SIC's: 381, 3822, 3823, 3824, part of 3829

14.02 Medical, Surgical, and Dental Instruments and Supplies

Includes processes related to the manufacture of surgical, medical, veterinary and dental instruments, apparatus, and supplies, including false teeth, wheelchairs, diagnostic equipment, and first aid supplies.

Related SIC's: 384

14.03 Watches, Clocks and Parts

Includes all processes of manufacturing and assembling watches, clocks, clockwork-operated devices, and parts.

Related SIC's: 387

14.04 Optical and Ophthalmic Goods

Includes processes of producing optical instruments and apparatus such as binoculars and magnifying instruments, and ophthalmic goods such as eyeglasses, contact lenses, frames, and parts.

Related SIC's: 383, 385

14.05 Photographic Equipment and Supplies

Includes all processes of producing photographic apparatus and equipment, including all types of cameras, film, parts, attachments, and accessories.

Related SIC's: 386

15.01 Computing and Related Machines

Includes all processes related to manufacture of electronic computing equipment; calculating and accounting machines, cash registers and other similar equipment.

Related SIC's: 3573, 3574

15.02 All Other Office and Business Machines

Includes all processes of producing typewriters and parts; scales and balances, except laboratory; office machines and devices not elsewhere classified such as duplicating and dictating equipment.

Related SIC's: 3572, 3576, 3579

15.03 Office Supplies

A "dummy" industry which collects and distributes the output of other industries for accounting ease.

16.01 Ordnance and Accessories

Includes all processes of producing and assembling small and large arms and ammunition.

Related SIC's: 348

16A02 Sporting Goods and Toys

Includes all processes of producing toys, games and amusements, and all types of sporting and athletic goods.

Related SIC's: 394

16B02 All Other Miscellaneous Products

Includes processes related to the manufacture of all products not classified in any of the above major groups such as jewelry, silverware, hard surface floor coverings, mortician's goods, musical instruments, matches, notions, fire extinquishers, neon signs, and umbrellas, among others.

Related SIC's: 39, except 394

17.01 Railroads and Related Services

Includes processes related to the provision of railroad services, including all line-haul freight and passenger transportation, railway express services, and the operation of switching and terminal facilities; also includes the rental of railroad cars. Does not include construction, maintenance and repair of roadbed, rails and buildings.

Related SIC's: 40,474

17.02 Local and Other Highway Passenger Transport

Includes processes related to the provision of all local and interurban highway passenger transportation, and for supplying terminal facilities.

Related SIC's: 41

17.03 Motor Freight and Warehousing

Includes processes related to providing for local or long-distance trucking services including transfer, storage, and warehousing and the operation of terminal facilities.

Related SIC's: 42, part of 4789

17.04 Water Transportation

Includes processes related to providing freight and passenger transportation on the open seas or inland waters, including marine cargo operations, terminal facilities, lighterage, towing, and canal operation.

Related SIC's: 44

17.05 Air Transport

Includes processes related to providing domestic and foreign air transportation, including airport operations and/or terminal facilities.

Related SIC's: 45

17.06 Pipelines

Includes processes related to providing for pipeline transportation of petroleum, natural gas, and other commodities. Does not include urban/suburban distribution systems for water and/or gas.

Related SIC's: 46

17.07 Transportation Services

Includes provision of services incidental to transportation such as forwarding and packing services, the furnishing of travel information and the arrangement of passenger and freight transportation, inspection and weighing services, packing and crating, and tollroad and bridge operation.

Related SIC's: 47, except 474, part of 4789

18.01 Telecommunication

Includes processes related to the furnishing of point to point communication services (except radio and television broadcasting, which are in Sector 21.02), including telephone, wire or radio telegraph, phototransmission, ticker tape operations, and transradio press services.

Related SIC's: 48 (except 483)

18.02 Electric Power

Includes processes related to the generation, transmission and distribution of electrical energy, including electricity generated by users.

Related SIC's: 491, part of 493

18.03 Gas

Includes processes related to the storage and distribution to final users of natural and synthetic gas.

Related SIC's: 492, part of 493

18.04 Water and Sanitary Services

Includes processes related to the collection, treatment, and distribution of water for all uses, including water supply systems for the purpose of irrigation; and processes related to the collection and disposal of refuse and wastes. Includes steam supply for power or heat.

Related SIC's: 494, 495, 496, 497, part of 493

19.01 Construction, Residences

Includes processes related to the designing, erecting, maintaining, and repairing of all single and multiple unit dwellings; also includes the performance of major alterations and remodelling of these units.

Related SIC's: parts of 15, 17, 6561

19.02 Construction, Nonresidential Buildings

Includes similar processes to 19.01, but for industrial, commercial, farm, and government buildings. Also includes construction of blast furnaces and other industrial structures.

Related SIC's: parts of 15, 17

19A03 Construction, Railroad

Includes processes related to railway roadbed construction including the laying of track, along with maintenance and repair of roadbeds and track.

Related SIC's: part of 1629

19B03 Construction, Pipelines

Includes processes related to the laying and wrapping of all pipelines, including maintenance and repair.

Related SIC's: part of 1623

19C03 Construction, Other Public Utility

Includes processes related to all other public utility construction, maintenance and repair including power lines, pumping stations, sewers, cable laying, and radio and TV transmission towers. Includes laying of gas utility distribution systems (from utility to user).

Related SIC's: part of 16

19A04 Construction, Highways

Includes processes related to the construction, maintenance and repair of roads, streets, sidewalks, guardrails, parking areas, and airport runways.

Related SIC's: 1611

19B04 Construction, Bridges

Includes processes related to the construction, maintenance and repair of bridges, viaducts, elevated highways, and railroad bridges.

Related SIC's: part of 1622

19C04 Construction, Dams

Includes processes related to the construction, maintenance and repair of dams, dikes, causeways, and other flood control projects.

Related SIC's: part of 1629

19D04 Construction, All Others

Includes processes related to construction, maintenance and repair of all other nonresidential buildings and facilities not listed above in 19A04-19C04 including canals and channels, docks, harbors, and jetties; subways,reservoirs, land drainage and other reclamation projects; ski tow erection; and blasting and debris removal services not classified above. Also includes drilling of oil, gas, and/or water wells.

Related SIC;s: part of 16

20.01 Wholesale and Retail Trade

Includes processes related to the provision of wholesale/retail services (trade margins) associated with delivery to plant gates or final destinations of all intermediate and final consumers of goods and services. Also includes eating places not integral to hotels or lodging places.

Important to note:

1. Technically, trade embraces services of break-bulk and title transfer.

2. Many related services are also included, such as brokerage of manufactured products (but not commodities) and commission merchandising.

3. In intermediate transactions, many do not involve trade intermediaries, being directly between producers and users.

4. Transportation margins are not in 20.01

5. Costs of the goods bought and sold are not included in output of 20.01, but only the trade margins that pay for services of (20.01).

Related SIC's: 50, 52-59, 7396

20XA2 Insurance

Includes the provision of insurance services by carriers of all types. To the extent possible, "insurance dollars" should reflect administrative costs, not premiums or claims.

Related SIC's: 63, 64

20XB2 Finance, Real Estate, and Advertising

Includes the provision of services by banks and trust companies, credit investment and other holding companies, securities and commodities brokers and dealers; lessors, lessees, buyers, sellers, agents, and developers of real estate; and services related to the preparation and placement of advertising, including commercial radio and TV programs.

Related SIC's: 60, 61, 62, 65, 66, 67, 731

20A05 Fracture Related Research and Development

Includes processes related to the performance of all fracture related research and development activities. Includes "pure" research in fracture mechanics, plus R&D directed toward fracture control, related instrumentation, non-destructive testing, etc.

Related SIC's: part of 739

20B05 All other Research and Development

Includes all research and development activities except those noted above. This is a special subdivision of new sector covering all R&D. The two will be combined for future activities involving Input/Output analysis.

Important to note:

1. 20A05 would go to zero in World II and would remain unchanged between World III and World I.

2. By definition, 20B05 is unchanged in Worlds II and III from World I.

3. Total R&D generally includes in-house as well as purchased R&D and is generally assigned to the funding or the benefitting column (not to the performing column).

4. Where the R&D benefits a particular industry -- regardless of how funded -- it may be ascribed to that column. E.g., agriculture is benefitted by the bulk of the USDA Extension Service R&D and therefore (if possible) should be shown on the R&D row of the several agricultural columns.

5. "Pure" research and social science research which cannot be ascribed to any particular buyer, will generally be shown in the institutional column related most closely to it:

   21.07, Medical
   21.08, Colleges and Universities
   Federal Government Expense (FD)

Related SIC's: part of 739

20C05 Environmental Cleanup

Includes processes related to environmental cleanup associated with all catastrophic natural or accidental events, excluding consideration of improper dumping or improper disposition of hazardous materials, etc. This is a special sector added for the fractures study.

Important to note:

1. This sector has nothing to do with cleaning up of old pollution, i.e., accumulated industrial pollution and/or waste dumps, etc.

2. The only cleanups involved are those associated with transportation accidents and/or rupture of storage vessels (such as gasoline storage tanks).

Related SIC's: parts of many

20D05 All Other Business and Professional Services

Includes provision of all other business services not included above, including data processing, personnel supply, management and consulting, equipment rental and leasing, commercial testing, legal, engineering, architectural, accounting, and selected commercial scientific and research activities.

Related SIC's: part of 73, 7694, 7699, 81, part of 89

20.06 Business Travel, Entertainment, and Gifts

A "dummy" sector which distributes goods and services associated with business travel, business entertainment and meals, and gifts to business associates.

Related SIC's: parts of many

21.01 Printing and Publishing

Includes all processes associated with the printing and publishing of newspapers, books, magazines, periodicals.

Related SIC's: 27

21.02 Radio and T.V. Broadcasting

Includes processes related to the dissemination of radio and T.V. programs, excluding the provision of program material and related services.

Related SIC's: 483

21.03 Hotels and Lodging Places

Includes the provision of commercial and institutional lodging services, including hotels, motels, tourist homes, boarding houses, trailer and sporting camps, campsites, and organizational lodging on a membership basis.

Related SIC's: 70

21A04 Personal Services

Includes provision of laundry, dry cleaning, photographic, barber and beauty, and funeral services.

Related SIC's: 72, excluding part of 725

21B04 Repair Services Except Auto

Includes shoe and watch repair, appliance and furniture repair, and all other personal repair services.

Related SIC's: part of 76, part of 725

21.05 Automobile Repair and Services

Includes provision of automotive repair, rental, leasing, painting, washing, towing and parking services to the general public. Also includes tire rebuilding and retreading.

Related SIC's: 75

21.06 Amusements

Includes provision of amusement, entertainment, and recreation services, including motion pictures, TV and radio program materials (sold to advertising, Sector 20XB2), theatrical productions, commercial sports, horse racing, public golf courses, museums, coin operated amusement devices, and other participatory or spectator events.

21.07 Medical and Health Services

Includes provision of medical, surgical, dental, psychiatric and other health services to persons, including nursing care facilities.

Related SIC's: 80

21.08 Educational Services and Nonprofit Organizations

Includes provision of all formal, academic, or technical education, including correspondence, commercial and trade schools, and libraries; also includes museums and art galleries and all membership organizations, including business, professional, and fraternal associations, labor unions, political organizations and noncommercial research institutes (e.g., The Brookings Institution).

Related SIC's: 82, 84, 86, 892

22.01 Post Offices

Includes provision of all postal and mail services.

Related SIC's: none

APPENDIX D. THE ROW RULES

The philosophy which led to the development of the so-called "Row Rules" is set forth in Chapter 4. This Appendix contains the details of all the rules in the way that they have been applied. These rules are arranged generally in terms of the matrices to which they apply and the matrix indication appears parenthetically with each rule's title. Note that the Scrappage Rule applies to both the A and B matrices and (even though procedurally it is the first rule applied to the A matrix) it appears in this Appendix as the last in the A matrix group.

The general order of arrangement is: A Matrix, B Matrix, R Matrix, and Final Demand.

Materials Rules
(A Matrix)

For each of the materials producing sectors discussed below, sets of row rules for Worlds II and III weight reductions have been formulated. Generally, these rules reflect the ability to design uniformly perfect materials at a safety factor of unity in World II and macroeconomic best practice, which employs all presently known skills and practices and which minimizes total cost to society, in World III (see Chapter V of the Phase I report for a more detailed discussion of the derivation of these rules). For many of the rules presented below, exceptions to each will be noted (i.e., weight reduction is not possible because e.g., a material thickness is dictated by wear, corrosion, aesthetics, etc.). For others, exceptions are accounted for as column specific changes, the explanations for which will appear on the column data sheets.

Development of the Materials Rule Concept

The development of the materials rules stems from the most fundamental definitions of Worlds II and III, and ties directly to the physical meaning of these hypothetical descriptions of the economy. In general, the material characteristics in either World II or World III are defined such that the useful yield strength will be increased over that of World I, and the quantities of material required would be decreased. The ratio of yield strength in either World to that of World I is conveniently expressed as

$$K_m^i = \frac{\mu - C^i\sigma}{\mu - B\sigma} \qquad (1)$$

where the index (i) denotes the appropriate World, and μ and σ are the mean and standard deviations, respectively, of yield strength for a class of materials.

In addition, design considerations require that a safety factor K_d^i be applied as a correction to strength. Thus, the strength of a material in World (i) becomes $K_m^i K_d^i \sigma_I$, where σ_I is the strength in World I.

A straightforward argument permits a translation from this general expression for World (i) strengths into World (i) weights of materials, the latter being the appropriate basis for the development and use of row rules. Intuitively, it is expected that strength increases by a factor of $K_m^i K_d^i$ would result in weight decreases by a factor $(K_m^i K_d^i)^{-n}$, where $n \leq 1$.

To evaluate n, we need to consider load distribution and component geometry. For example, in a tension member of length L and supporting a load P, we have

$$P = \sigma_I A_I = (K_m^i K_d^i)\, \sigma_I A^i \tag{2}$$

where A_I is the cross section in World I and A^i is the cross section in World (i). The weight of the tension member is given as

$$W_I = \rho L A_I ;\; W^i = \rho L A^i \tag{3}$$

where ρ is the density. Combining Equations (2) and (3), the proportionate weights are

$$W^i / W_I = (K_m^i K_d^i)^{-1} \tag{4}$$

or n = 1. If a solid cylindrical bar is loaded in bending, a similar calculation gives n = 2/3. For a flat disc supported along its rim to represent a platform and point-loaded, n = 1/2. Consideration of several other geometries suggests that $1 \geq n \geq 1/2$ in all cases. In the absense of detailed data regarding all possible load-bearing geometries, we have arbitrarily chosen an "average" value of n = 3/4.

The specific choices of C^i (and, hence, K_m^i) and K_d^i can now be made to result in initial values of the weight reduction that is applied in the row rules.

As was noted in Chapter II, the no-fracture World cannot be based on the assumption that fracture and massive deformation do not occur in an absolute sense. Such an assumption would lead to values of the total cost of fracture which are totally unrealistic.

In order to define a more tenable base from which to measure fracture costs, several conditions have been imposed on the materials and design which characterize World II. In regard to material usage, existing standards dictate that most steels (which we use as a reference) are selected to have minimum yield strengths at that value which is 3.7 standard deviations below the mean.* The definition of World II permits usage at 4.0 standard deviations above the mean.

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*Metals Handbook, Ninth Edition, Volume 1, ASM (1978)

In addition, the definition and specification of World II includes perfect knowledge of material characteristics and their response to imposed stresses; hence, a safety factor of unity can be applied to all structures. It follows from these "textbook" definitions that for most applications in World II, the dimensions of steel members could be reduced substantially -- to 51 percent of the dimensions presently employed in World I. This material reduction can be achieved in all cases except where the application carries with it constraints imposed by stiffness or other characteristics of the material (such as electrical conductivity).

Similarly, in World III, it is assumed that the use of best fracture control practices would lead to the use of steels having properties 2.0 standard deviations below the mean. A representative safety factor of 1.5 has been assumed for various metals in World I*, and a range of safety factors of 1.15-1.5 (average 1.3) has been identified as appropriate for the ultimate stress in commercial aircraft. Inasmuch as this sector is believed to exhibit general application of best practices, a value of

$$K_d^{III} = 1.5/1.3 = 1.15$$

has been adopted. Coupled with the choice of K_m^{III}, it has been calculated that material reductions to 81 percent of present specifications could be realized.

It is recognized that these reductions by 49 and 19 percent (the so-called 49/19 rules) tend to understate the extent to which material adjustments should be made, as they take into account only the lower limits of safety factors that are commonly employed. Present designs for a number of different structures use large safety factors, and their reduction to unity would be reflected in an even larger reduction in materials. However, in keeping with the overall thrust of this program, conservative estimates of reductions (and, hence, conservative estimates of the cost of fracture) have been made.

Application of the Metals Rules

All producing sectors which buy primary metals (7A,B,C,01, 7.03, 7 x 04) will buy 49 percent less in World II and 19 percent less in World III. Note that the material weight savings accrue to the fabricating sector. For example, lighter weight I-beams put in place by one of the construction sectors do not represent a material savings to that construction sector. The construction sector buys I-beams from sector 8.A05, and 8.A05 appreciates the savings in metal due to weight reduction. The construction sector thus purchases the same number of I-beams as it did

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*H. D. Gerlach, International Journal of Pressure Vessels and Piping, Volume 8, pp 283-302 (1980).

before at the same price as before. The only exceptions would result from design changes which would e.g., permit wider beam spacing and therefore require fewer beams.

Exceptions to the -.49/.19 rule include the following columns:

Sector	Title	World II	World III	Notes
8.03	Metal sanitary ware and plumbing fittings	---	---	WI materials are already as thin as can be fabricated; also corrosion related
8.04	Nonelectric Heating Equipment	-.29	-.05	Limitations due to stiffness requirements
8B05	Boiler Shop Products	-.25	-.10	Corrosion allowance
8.07	Other fabricated metal products	-.05	---	Stiffness requirements
0.01	Engines & Turbines	-.25	-.10	Limitations due to stiffness, temperature and heat flow requirements
10.02	Construction machinery	-.37	-.14	Balance/ballast requirements
10.03	Mining machinery	-.37	-.14	Partially stiffness and wear requirements; partially ballast
10.06	Industrial trucks and tractors	-.37	-.14	Balance/ballast requirements
10.07	Metalworking machinery	-.25	-.10	Partially stiffness limited (e.g., rolling mill frame thickness); partially wear limited (e.g., cutting and forming tools)
10.08	Special industry machinery	-.37	-.14	Stiffness and corrosion requirements
11.01	Motor vehicles and parts	-.49	-.14	Movement toward best practice by 1978
11.02	Aircraft and parts	-.25	---	W II stiffness requirements; already at W III best practice
11.03	Ship and boat building	-.49	-.14	W III stiffness requirements
12.03	Industrial controls, transformers	---	---	Electrical rather than structural limitations (e.g., can't change amount of steel in transformer core)
14A01	Fracture Control Instruments	-.49	---	At W III best practice
16.01	Ordnance and accessories	-.25	-.10	Stiffness/mass constrained; some W III best practice already exists
16A02	Sporting goods and toys	-.25	-.10	Stiffness/mass constrained (e.g., tennis racquets, golf clubs)

The above exceptions to the -.49/.19 rule apply to all metals used as inputs to each of the column sectors. Additional exceptions for specific metal inputs include:

- No material savings of 7X04 into all sector 12's, 13's, and 15's. The 7X04 inputs into these sectors are primarily for wiring. Because of conductivity constraints, no material savings can be realized.
- No material savings of 7X04 and 7C01 into 16B02 (Miscellaneous Products). These primarily represent precious metal inputs into jewelry and silverware, and stainless steel into tableware. Weight savings would not occur because of personal taste considerations.
- Other exceptions such as -.25/.10 of 7A01 into 19A03 (Railroad Construction) because of rail stiffness limitations are accounted for as column specific changes.

Special Treatment of Ceramic and Related Materials

Unlike metals, there are no sectors that produce unformed ceramic materials and sell them to fabricating sectors. Instead, most of these sectors (disaggregations of 6.01 and 6.03) both refine and form the material. Therefore, reductions which take the forms of "row rules" in metals (7.01, 7X04, 7.03) inputs into fabrication sectors (8's, 9's, etc.) must be treated in a different manner.

Glass. Glass equivalents of row rules involve reductions in inputs of glass making materials (from 2.06, 2.07 and 5.03) and energy (from 5.01, 18.02 and 18.03) into 6A01, 6B01 and 6D01. This allows reduction of World II glass content of formed items, which then go unchanged into other processes. There are no changes in World III.

No equivalent change is made in 6C01, which buys flat glass (already subject to reduction) from 6A01.

World II material characteristics allow 30 percent reductions in 6A01 and 6B01, many uses of which are stiffness limited. Even more of outputs of 6D01 are limited by stiffness, insulation, thickness, or aesthetic aspects, leading to a 7.5 percent reduction.

Ceramics. With the exception of readymix concrete (part of 6B03), the ceramic sectors (6A03, structural concrete products in 6B03, 6C03, and 6D03) should be treated in a manner similar to the glass sectors (disaggregated 6.01).

Readymix Concrete. Across the row 6B03, reductions in inputs of readymix should be made in World II only:

Since readymix is approximately 60 percent of 6B03 total output and World II material characteristics are thought to permit a 4 percent reduction in inputs over World I, all row entries should be reduced by .024 (multiplied by .9760). The only exception is the 6B03 diagonal.

Plastics Rule - Row P.07

The material rule for plastics is split into four ranges of possible materials savings:

W II = -.30/W III = -.125
W II = -.20/W III = -.08
W II = -.10/W III = -.04
W II = -.00/W III = -.0

As all of the plastics fabricating sectors buy their materials from Sector P.07, any fracture relevant material savings are treated reductions across the P.07 row. Also noted is the fact that plasticizers and chemical additives which affect the strength of plastics are also produced in P.07.

Given the wide range of plastics produced as well as their different characteristics, it is difficult to generalize a single rule as it applies to each sector. However, by emphasizing the degree to which each sector's plastics applications are strength relevant (as opposed to e.g. waterproofing, sealing, filling a space, providing a decorative service, insulating, etc.), it is possible to categorize potential material savings for the average of each sector's major uses. Below are the expected P.07 savings by column sector.

.30/.125:	PA15						
.20/.08 :	5A06	PB15	6B01	6C01	8.06	16A02	16B02
.10/.04	2X02	4.02	4.08	PC15	10.08	12B07	14.04
	3A01	4.03	5.12	6D01	11.01	13.01	15.01
	3B01	4XA5	P.13	6A04	11.02	13 02	15.02
	3X05	4XB5	PA14	8.02	11.03	13.03	
	3B07	4.07	PB14	8.07	11.05	14.02	

Zero:

3.02	P.07	7.03	8C05	all 12's	16.01	20A05
3X03	6B04	7X04	9.01	except 12B07	17.06	20B05
5.03	7A01	8.03	9.03	14A01	17.07	20D05
5B06	7B01	8A05	10.04	14B01	19.02	21.01
5X10	7C01	8B05	10.07	14.03	20.01	21.06

Wood Rule - Row 4.01

It was decided by Battelle experts that materials characteristics allow general reductions in the following amounts of lumber (furnished by Sector 4.01):

W II	-	15%	or	X	0.85
W III	-	7.5%	or	X	0.925

This applies to all sectors using inputs from Sector 4.01 except:

4.03 } stiffness limited
4XA5 asthetics/space }

Transportation Rules for Reduction in Material Weights

(A Matrix)

Given the potential weight savings in the material rules described above, costs of transportation associated with the delivery of inputs to each sector's plant gate will be reduced. Inputs include the primary materials themselves (except in those cases where a sector's products were either not affected by a given material rule or which did not receive the full rule application, e.g., Sector 8.03), machinery and equipment and replacement parts for maintenance and repair of each producing sector's capital (a similar rule will apply toward transport costs associated with delivery of capital goods in the B matrix), and all forms of component parts that each sector assembles to complete its own product (as with the primary material inputs, account is taken of those components which are unaffected by or only partially affected by the materials rules). Where possible, sectors with similar input weight reductions have been grouped together for application of the transport savings rule.

> Example: For all Sector 1's, about two percent of all input requirements are weight sensitive. Divide the weight sensitive proportion by two, subtract the difference from 1.0 and apply the result to each sector's coefficients for Sectors 17.01, 17.03, and 17.04 to arrive at W II transport savings; similarly apply .25 of the W II savings to arrive at W III transport savings Thus, for all Sector 1's:

$$.02 \div 2 = .01$$

$$1.0 - .01 = .99 \text{ for W II}$$

$$.01 \times .25 = .0025$$

$$1.0 - .0025 = .9975 \text{ for W III}$$

Sectors	W II Multiplier	W III Multiplier
1's	.99	.9975
2's	.90	.9750
3A01, 3B01	.90	.9750
3A07	.65	.9125
3.02, 3X03, 3X05, 3B07, 3X08	.99	.9975
4.01, 4.02, 4.03, 4.07, 4.08	.99	.9975
4.04	.95	.9875
4XA5, 4XB5	.80	.9500
5.01, 5.02, 5.03, 5X04, 5A06, 5B06, 5.09	.98	.9950
5X10, 5.12	.97	.9925
all P's except P.13	.99	.9975
P.13	.94	.9850

Sectors	W II Multiplier	W III Multiplier
all 6's, except 6.03's	.99	.9975
6A03, 6B03, 6C03, 6D03	.96	.9900
all 7's	.99	.9975
8.01, 8.02	.75	.9375
8.03	.98	.9950
8.04, 8A05	.80	.9500
8B05	.35	.9625
8C05, 8.06	.75	.9375
8.07	.98	.9950
9.01	.90	.9750
9.02, 9.03	.80	.9500
all 10's	.80	.9500
11.01	.88	.9700
11.02	.98	.9950
11.03	.88	.9700
11.04	.80	.9500
11.05	.90	.9750
12.01	.95	.9875
12A02, 12B02	.85	.9625
12.03	.99	.9975
12.04	.97	.9925
12.05	.70	.9250
12.06, 12A07, 12B07	.95	.9875
13.01, 13.02	.88	.9700
13.03	.95	.9825
14A01, 14B01, 14.02	.90	.9750
14.03	.97	.9925
14.04, 14.05	.98	.9950
15.01	.95	.9875
15.02	.88	.9700
all 16's	.90	.9750
all 17's	.99	.9975
all 18's	.99	.9975
19.01, 19.02	.88	.9700
19A03, 19C03	.80	.9500
19B03	.60	.9000
19A04, 19B04	.88	.9700
19C04, 19D04	.90	.9750
all 20's	.99	.9975
all 21's	.99	.9975

Maintenance and Repair Rules
(A Matrix)

The following rules will apply as row modifications for capital-generating sectors in the A matrix, to selected column sectors, but in no instance will the modification apply to the diagonal (row and column cell of the same sector).

Rule #1.

- For all construction sectors in the A matrix (which are automatically M/R), multiply selected row entries by .995 in W II; note that only rows 19.02 and 19A04 should perform M&R for any other 19 sector.
- W III is anticipatory, i.e., anything done would be done to e.g. increase life, etc. Therefore, multiply all 19's by 1.0025.

Applicable sectors: 19.01, 19.02, 19A03, 19B03, 19C03, 19A04, 19B04, 19C04, 19D04.

Rule #2.

- For 21B04 (Repair Services), multiply all entries by .9000 across the row for W II; i.e., about 10% of this repair and maintenance service is fracture related.
- For W III, multiply all 21B04 entries by .9500 across the row because, e.g., a) a typewriter is made better, b) a typist uses it better, and c) typewriter M/R makes better repairs.

Applicable Sectors: 21B04

Rule #3.

- For selected sectors, multiply row entries by .9900 for W II; this represents fracture relevant M/R parts, supplies, and labor.
- For W III, multiply by .9950 across row because "Best Practice" affects original manufacture, use, and M/R services.

Applicable Sectors: 9.01, 9.02, 9.03, 10.03, 10.07, 12.01, 12B02, 12.03, 12.05, 12A07, 12B07, 13.01, 13.03, 14A01, 14B01, 14.02, 14.03, 14.04, 14.05

Rule #4.

- For selected row sectors (those which are less component/supplies oriented than in #3 above), multiply by .9000 across row for W II; in-service use of equipment/machinery in these sectors generates significant parts replacement that are fracture relevant.
- For W III, multiply by .9500 because "Better Practice" affects original manufacture, use, and M/R services.

Applicable Sectors: 10.01, 10.02, 10.04, 10.05, 10.06, 10.08, 11.01, 11.02, 11.03, 11.04, 11.05, 12A02, 15.01, 15.02.

Rule # 5.

- For 21.05 (Automotive Repair), fracture relevant M/R is estimated to be 1% of total M/R, which represents 60% of the sector's output (excludes parking, painting, washing, towing, leasing, etc.), for W II, multiply row entries by .9940.
- For W III, multiply 21.05 row entries by .9970.

NOTE: Sector 12.04 (light bulbs) is excluded from the above rules because of its "consumable characteristic; Sector 13.02 (household appliances) is excluded because most of its M/R is performed in 21B04; and sectors 16.01 (ordnance) and 16A02 (sporting goods & toys) are excluded because their outputs are non M/R related.

The above M/R rules as they apply to specific row Sectors are summarized below.

Multipliers for M & R Rules

Sector	Rule #	Title	W II	W III
9.01	3	Engines & Turbines	.9900	.9950
9.02	3	Gen Indus Mach & Equip	.9900	.9950
9.03	3	Machine Shop Prod	.9900	.9950
10.01	4	Farm Machinery	.9000	.9500
10.02	4	Construction Machinery	.9000	.9500
10.03	3	Mining Machinery	.9900	.9950
10.04	4	Oil Field Machinery	.9000	.9500
10.05	4	Material-Handling Mach Except Truck	.9000	.9500
10.06	4	Indust Trucks & Tractors	.9000	.9500
10.07	3	Metal Working Machinery	.9900	.9950
10.08	4	Specl Industry Machinery	.9000	.9500
11.01	4	Motor Vehicles & Parts	.9000	.9500
11.02	4	Aircraft & Parts	.9000	.9500
11.03	4	Ship & Boat Bldg & Repairs	.9000	.9500
11.04	4	Locoms & Rail & Rpd Trnst	.9000	.9500
11.05	4	Cycles, Trailers, Etc.	.9000	.9500
12.01	3	Elec Measuring Instruments	.9900	.9950
12A02	4	Elec Motors & Generators	.9000	.9500

Row Sector	Rule #	Title	W II	W III
12B02	3	Other Elect Motrs & Genrtrs	.9900	.9950
12.03	3	Indus Controls, Transformers	.9900	.9950
12.05	3	Light Fixt & Wiring Devices	.9900	.9950
12A07	3	X-Ray Equipment	.9900	.9950
12B07	3	Other Misc Electric Mach	.9900	.9950
13.01	3	Service Industry Machinery	.9900	.9950
13.03	3	Radio, TV & Commun Equip	.9900	.9950
14A01	3	Fracture Control Instrum	.9900	.9950
14B01	3	Other Scientific Instrum	.9900	.9950
14.02	3	Med, Surgcl, Dental Instrum	.9900	.9950
14.03	3	Watches, Clocks & Parts	.9900	.9950
14.04	3	Optical & Ophthalmic Goods	.9900	.9950
14.05	3	Photo Equip & Supplies	.9900	.9950
15.01	4	Computing & Related Machines	.9900	.9950
15.02	4	Other Office & Busin Machines	.9000	.9500
19.01	1	New Construction, Nonfarm Residences	.9950	1.0025
19.02	1	New Construction, Nonresid-dential Buildings	.9950	1.0025
19A03	1	New Construction, Railroads	.9950	1.0025
19B03	1	New Construction, Pipelines	.9950	1.0025
19C03	1	Other Public Utility Constr	.9950	1.0025
19A04	1	New Construction, Highways	.9950	1.0025
19B04	1	New Construction, Bridges	.9950	1.0025
19C04	1	New Construction, Dams	.9950	1.0025
19D04	1	New Construction, All Other	.9950	1.0025
21B04	2	Repair Service, Except Auto	.9000	.9500
21.05	5	Automobile Repair & Service	.9940	.9970

20A05 Fracture R&D Row Rules

(A Matrix)

In World II, entries for row 20A05 go to zero.
In World III, corresponding row entries remain unchanged.
There are no exceptions.

Environmental Cleanup Rule (Sector 20C05)

(A Matrix)

Entries across row 20C05 in the A matrix affect only 12 Sectors in World I. These are sectors that are subject to accidents of transportation and/or storage necessitating emergency cleanup of spills of hazardous materials. They do not involve improper disposal or other similar forms of pollution.

In Worlds II and III these sectors are still subject to emergencies due to catastrophic natural events and events of human error, vandalism, etc., that are outside our scope. Therefore, the reductions in inputs of 20C05 (across the row) in World II are based on data collected for the supplemental models. On the basis of fragementary information, we have assumed that the reductions in World III are one-half those shown for World II.

For column sectors 2A05, 2B05, 5.01, 5.03, 5X02, 17.06, and 18.03, row entries are reduced by 7.3% (i.e. multiplied by .927) in World II and by 3.65% (multiplied by .9635) in World III.

For column sector 17.01, corresponding changes are -25.3% and -12.65% (multiplied by .747 and .8735), respectively.

For column sectors 17.03 and 18.02, corresponding changes are -0.5% and -0.25% (multiplied by .995 and .9975).

For column sector 17.04, changes are -0.7% and -0.35% (.993 and .9965).

For column sector 17.05, changes are -7.8% and -3.9% (.922 and .961).

Inspection Rule
(A Matrix)

Fracture relevant inspection of capital equipment, structures, inputs, work in progress, or finished goods is also treated as a "row" rule. For both Worlds II and III, estimates of labor savings/dissavings related to lower/higher inspection requirements are applied to the labor component of each sector's value added. In applying the row rule, only inspection performed by the producing (column) sector's labor is considered. In cases where special circumstances warrant, additional inspection adjustments are made in other rows, e.g., ultrasonic inspection of petroleum refinery equipment, which is treated as a Sector 5.01 purchase from Sector 20D05. Summarized below are the sector specific inspection changes for Worlds II judgments concerning best practice state of the art.

The first part of the rule details that follow consists of the proportion by which the labor component of value added is reduced (-) or increased (+). The second part consists of the proportion of value added that is labor costs. Thus, in Sector 1.01 the World II adjustment is shown (in the first listing) as -01; the labor component is shown (in the second listing) as .1322. The final adjustment is made by multiplying the sector's value added coefficient by 1-(.01 x .1322). This is (1-.0013) or .9987. For Sector 2A04 the World III adjustment is shown (in the first listing) as +.07; the labor component of value added is shown (in the second listing) as .5189. The final adjustment is made by multiplying the sector's value added coefficient by 1+(.07 x .5189) this is (1 + .0363) or 1.0363.

Adjustment to Labor Component of Value Added

Sector	Title	World II	World III	Notes
1.01	Livestock & livestock products	-.01	-.005	low, mainly for capital equipment, W III lower due to improvement in capital equipment
1.02	Field & orchard crops	-.01	-.005	low, similar to 1.01
1A03	Forestry products	-.005	-.0025	very low, mostly for equipment
1B03	Fishery Products	-.03	-.01	moderate, mostly capital in fishing industry
1.04	Services to agriculture, forestry & fishery	-.01	-.005	low, mostly capital equipment
2.01	Iron & ferro alloys ores mining	-.005	-.0025	very low, mostly capital equipment
2X02	Nonferrous ores mining	-.005	-.0025	very low, similar to 2.01
2A04	Underground coal mining	-.05	+.07	moderately high, mostly for prevention of roof falls, balance for equipment; best practice likely to increase roof bolting

Sector	Title	World II	World III	Notes
2B04	Strip coal mining	-.005	-.0025	very low, mostly equipment
2C04	Other coal mining	--	--	negligible, ignore
2A05	Crude petroleum	-.02	-.005	moderate, essentially all capital; W III reduction due to best practice improvement in equipment
2B05	Natural gas	-.02	-.005	moderate, similar to 2B05
2.06	Stone & clay	-.005	-.0025	very low, mostly capital
2.07	Chemical & fertilizer minerals	-.005	-.0025	very low, same as above
3A01	Beverages	-.03	-.01	moderate, mostly inputs/work in progress (glass containers; less in W III due to shifting toward metal cans & plastics
3B01	All other food & kindred products	-.01	-.005	low, largely inputs/work in progress (glass containers); W III shift to metal/plastics also
3.02	Tobacco manufactures	-.01	--	low, 50/50 split between work in progress/capital; W III inspection up for work in progress & output offset by decline in equipment inspection
3X03	Leather & Leather Products	-.01	+.0075	low, mostly work in progress & output, capital small; W III inspection up for work in progress and output, down for capital
3X05	Fabrics, yarns, threads & soft floor coverings	-.10	--	moderately high, mostly work in progress, some capital; no change in W III
3A07	Metal tire cord	-.03	+.005	moderate, mostly output, some capital; inspection labor up in W III
3B07	Nonmetallic tire cord & miscellaneous textile goods	-.03	+.005	moderate, similar to 3A07
3X08	Apparel & other fabricated products	-.005	--	very low, for both output & capital; W III increases for output offset by decrease for capital
4.01	Sawmills & planing mills	-.01	+.005	low, mostly capital; increase in inspection of inputs more than offsets decrease for better equipment

Sector	Title	World II	World III	Notes
4.02	Veneer & plywood	-.005	-.001	very low, mostly capital, some output; W III, capital down output inspection up
4.03	All other lumber & wood products, except containers	-.005	-.0025	very low, mostly capital
4.04	Wooden containers	-.005	-.0025	very low, similar to 4.03
4XA5	Wooden furniture & fixtures	-.01	-.005	low, similar to 4.01
4XB5	Metal furniture & fixtures	-.01	-.005	low, similar to 4XA5
4.07	Pulp, paper & paper products, except containers	-.01	-.005	low, similar to 4XB5
4.08	Paperboard containers & boxes	-.02	--	low, capital & output; W III increase of output inspection offsets less for inspection of better capital
5.01	Petroleum refining & related products	-.03	-.01	moderate, all for capital
5.02	Paving mixtures & asphalt products	-.03	-.01	moderate, similar to 5.01
5.03	Industrial inorganic & organic chemicals	-.02	-.01	low, all for capital
5X04	Agricultural chemicals	-.01	--	low, part capital, part packaged output; W III increase for output offset by decrease for better equipment
5A06	Adhesives	-.01	--	low, similar to 5X04
5B06	All other misc chemical products	-.01	--	low, similar to 5X04
5.09	Drugs	-.02	-.005	low, part packaged output, part capital; W III increase in output inspection partially offset by decrease in equipment inspection
5X10	Cleaning & toilet preparations	-.01	--	low, similar to 5X04
5.12	Paints & allied products	-.01	-.005	low, mostly capital
P07	Plastic materials resins & synthetic rubber	-.03	-.01	moderate, all for capital
P08	Organic manmade fibers	-.03	-.005	moderate, mostly capital but some for work in progress; W III capital inspection reduced but no change in work in progress

Sector	Title	World II	World III	Notes
P13	Tires & inner tubes	-.02	--	low, split between capital & product (both work in progress & output); W III product inspection increase offsets equipment decrease
PA14	Industrial rubber belts	-.03	+.01	moderate, 2/3 for product, 1/3 for capital; W III product inspections increase, those for capital decrease
PB14	All other rubber products	-.01	--	low, similar to P13, but less
PA15	Plastic pipe	-.02	+.005	low, split between capital & output; W III output inspection increases more than equipment inspection decrease
PB15	Plastic containers	-.015	+.01	low, 2/3 capital, 1/3 output; W III output inspection increases more than equipment inspection decrease
PC15	All other manufactured plastic products	-.01	+.005	low, similar to PA15, but less
6A01	Flat glass	-.02	-.005	low, mostly capital, some output; no change in W III output inspection (already at best practice) but modest decline in capital inspection
6B01	Glass containers	-.03	-.01	moderate, split between output & capital
6C01	Automobile & truck windshields	-.01	--	low, split between output & capital; essentially no change in W III as capital equipment is much less complicated than in 6A01 or 6B01 and output inspection still needed
6D01	All other glass products	-.05	-.02	moderate, 2/5 for capital, 3/5 for output; W III best practice allows savings in both
6.02	Hydraulic cement, lime, & gypsam products	-.01	--	low, mostly capital; W III equipment inspection decrease offsets output inspection increase
6A03	Structural clay products, except clay structures	-.03	-.01	moderate, 2/3 output, 1/3 capital; W III reductions for both
6B03	Structural concrete products & ready mixed concrete	-.01	+.005	low, 1/4 capital, 3/4 output; W III modest increase in output inspection, equipment best practice negligible

Sector	Title	World I	World III	Note
6C03	Pottery, whiteware & porcelain products	-.03	--	moderate, 1/3 capital 2/3 product (both work in progress & output); W III equipment inspection reduction offset by small increase in product inspection
6D03	Clay & nonclay refractories	-.03	-.005	moderate, 1/3 capital, 2/3 for product (both work in progress & output); W III has lower equipment inspection but modest increase in product inspection
6A04	Abrasives, including grinding wheels	-.01	+.005	low, 3/4 for product, 1/4 for capital; no W III change in equipment inspection but product inspection increases
6B04	All other store & non-metallic mineral products	-.01	--	low, split between capital & output; W III product inspection increase offsets equipment decline
7A01	Carbon steel	-.01	+.0025	low, mostly capital; W III has small increase in equipment inspection
7B01	Alloy steel	-.01	+.0025	low, mostly for capital; W III has small increase in capital equipment inspection
7C01	Stainless steel	-.01	--	low, primarily capital, some for output; W III equipment inspection decline offsets output inspection increase
7.03	Aluminum	-.03	+.01	moderate, mostly output, some for equipment; W III output inspection increases
7x04	All other nonferrours metals	-.01	--	low, split between capital and products (work in progress & output; W III reduction in equipment inspection offsets increase in output inspection
8.01	Metal cans	-.01	+.005	low, split between capital & product (inputs, work in progress, and output); product inspection increases more than offset reduction of equipment inspection in W III
8.02	Metal barrels, drums & pails	-.01	+.005	low, mostly for product (inputs, work in progress, output), remainder for equipment; no W III change for equipment, but slight increase for product

Sector	Title	World I	World III	Notes
8.03	Metal sanitary ware & plumbing fittings	-.03	+.005	moderate, mostly for work in progress & output; slight W III reduction in capital inspection, but more than offset by increase in product best practice (switch to castings from forgings)
8.04	Non electric heating equipment	-.01	+.005	low, mostly for inputs, work in progress, output; W III inspections increase
8A05	Structural metal products	-.01	+.005	low, nearly all for inspection of inputs, work in progress, output; W III inspections increase
8B05	Boiler shop products & pressure vessels	-.01	+.005	low, similar to 8A05
8C05	All other fabricated structural products	-.005	+.0025	very low, essentially for output; W III inspection up slightly
8.06	Screw machine products, stampings & forgings	-.005	-.0025	very low, mostly for capital; W III better equipment requires less inspection
8.07	Other fabricated metal products	-.005	-.0025	very low, mostly capital, similar to 8.06
9.01	Engines & turbines	-.01	+.0025	low, split between capital and product (work in progress and output); W III shift from forgings to castings increases inspection needs
9.02	General industrial machinery & equipment	-.005	+.0025	very low, primarily output; W III requires slightly more output inspection
9.03	Machine shop products	-.005	+.0025	very low, split between capital & products (work in progress & output); W III reflects increase in product inspection
10.01	Farm machinery	-.01	+.0025	low, split between products (work in progress & output) and capital; W III decline in capital inspection more than offset by increased inspection of products
10.02	Construction machinery	-.01	+.0025	low, similar to 10.01
10.03	Mining machinery	-.01	+.0025	low, similar to 10.01
10.04	Oil field machinery	-.01	+.0025	low, similar to 10.01
10.05	Materials-handling machinery, except trucks	-.01	+.0025	low, similar to 10.01

Sector	Title	World II	World III	Notes
10.06	Industrial trucks & tractors	-.01	+.0025	low, similar to 10.01
10.07	Metalworking machinery (including cutting tools)	-.01	+.0025	low, similar to 10.01
10.08	Special industry machinery	-.01	+.0025	low, similar to 10.01
11.01	Motor vehicles & parts	-.03	+.01	moderate, 2/3 for products (input, work in progress, output), 1/3 for capital; W III equipment best practice reduces inspection, but that for product increases them substantially
11.02	Aircraft & parts	-.25	--	high, primarily for product (input, work in progress, output); W III best practice increases some inspections, reduces others to yield net inspection change of zero
11.03	Ship & boat building repair	-.03	+.01	moderate, preponderantly work in progress & output W III best practice results in increased inspection, e.g., welding, leakage prevention
11.04	Locomotives, rail cars & streetcars	-.01	+.005	low, principally for work in progress & output; W III requires increased inspection
11.05	Motorcycles, bicycles, trailer coaches, etc.	-.01	+.005	low, mostly for output; W III requires increase inspection
12.01	Electrical measuring instruments	--	--	negligible, no changes warranted
12A02	Electric motors & generators for power plants	-.01	+.005	low, primarily for output; W III needs increased inspection
12B02	All other electric motors & generators	-.01	+.005	low, similar to 12A02
12.03	Industrial controls, transformers, etc.	-.01	+.005	low, similar to 12A02
12.04	Electric lamps	-.03	-.01	moderate, mostly for inputs work in progress, & output; W III process best practice reduces inspections
12.05	Lighting fixtures & wiring devices	-.005	+.0025	very low, mostly for output; W III requires slight increase in inspection

Sector	Title	World I	World III	Notes
12.06	Electronic components & accessories	-.005	-.0025	very low, largely for capital equipment, some for output (circuit continuity); all W III inspections reduced by best practice use
12A07	X-ray equipment	-.005	+.0025	very low, mostly for work in progress (x-ray tubes); W III inspections up slightly
12B07	All other misc electrical machinery	-.01	+.0025	low, mostly for output, some for equipment; W III output inspections increase
13.01	Service industry machinery	-.01	+.005	low, mostly output, some for capital (enamelling ovens, drying ovens); W III inspections increase
13.02	Household appliances	-.01	+.005	low, largely for work in process & output; W III inspections increase
13.03	Radio, T.V., & communication equipment	-.01	+.005	low, predominantly for output; W III inspections increase
14A01	Fracture control instruments	-.01	+.005	low, similar to 13.03
14B01	All other scientific measures & controls	-.01	+.005	low, similar to 13.03
14.02	Medical, surgical & dental instruments & supplies	-.01	+.005	low, similar to 13.03
14.03	Watches, clocks & parts	-.01	+.005	low, similar to 13.03
14.04	Optical & ophthalmic goods	-.02	-.01	low, primarily for inputs, work in process, and output; W III best practice reduces inspection needs
14.05	Photographic equipment & supplies	-.01	+.005	low, for equipment and output; W III output inspections up
15.01	Computing & related machines	-.01	-.005	low, split between work in process & capital; W III best practice reduces inspections of both
15.02	All other office & business machines	-.01	-.005	low, similar to 15.01
16.01	Ordnance & accessories	-.01	+.005	low, mostly work in process (costings & forgings); W III inspections up because of more costings
16A02	Sporting goods & toys	-.005	--	very low, mostly for output; W III no change

Sector	Title	World I	World III	Notes
16B02	All other misc products	-.005	+.0025	very low, mostly for output; W III inspections increase slightly
17.01	Railroads & related services	-.01	+.005	low, largely for capital; W III best practice reduces inspection needs of equipment, but counterbalanced by more inspection of right of way
17.02	Local & intercity highway passenger transport	-.01	-.005	low, similar to 17.01, but W III inspection declines
17.03	Motor freight & warehousing	-.01	-.005	low, similar to 17.02
17.04	Water transportation	-.01	-.005	low, similar to 17.02
17.05	Air transport	-.03	-.01	moderate, essentially all for capital equipment; W III equipment best practice reduces inspection need
17.06	Pipelines	-.05	-.02	high, primarily for capital (on-line compressors & pumping stations); W III equipment best practice reduces inspection needs
17.07	Other transportation services	-.015	--	low, mostly capital, but some "output" (inspection, packing & crating services are part of this sector);
18.01	Telecommunication	-.005	-.0025	very low, all for capital; W III better equipment reduces inspection needs
18.02	Electric Power	-.02	-.01	low, all for capital; W III best practice reduces inspections
18.03	Gas	-.01	-.005	low, all for capital; W III best practice reduces inspection needs
18.04	Water, sanitary services, & steam	-.01	-.005	low, similar to 18.03
19.01	New construction, nonfarm residences	-.01	+.005	low, essentially all for products (input, work in progress, output); in W III, inspections increase all around
19.02	New construction, nonresidential buildings	-.03	+.01	moderate, mostly for work in progress, some for inputs and output; W III work in progress and output inspections increase
19A03	New construction, railroad	-.03	+.01	moderate, mostly on work in progress; W III inspections increase

Sector		World I	World III	Notes
19B03	New construction, pipeline pipeline	-.05	+.01	high, similar to 19A03, but more inspection required
19C03	Other public utility new construction	-.02	+.01	low, mostly work in progress; more W III inspections
19A04	New construction, highways	-.015	+.005	low, 2/3 work in progress & inputs, 1/3 capital; W III decline in capital inspection offset by increases in work in progress & input inspection
19B04	New construction, bridges	-.01	+.005	low, similar to 19A04
19C04	New construction, dams	-.005	-.0025	very low, mostly for capital equipment; W III best practice equipment reduces need for inspection
19D04	All other new construction	-.01	-.005	low, mostly capital, especially drillings; W III better equipment reduces inspection needs
20.01	Wholesale & retail trade	--	--	negligible, ignore
20XA2	Insurance	--	--	negligible, ignore
20XB2	Finance, real estate & advertising	--	--	negligible, ignore
20A05	Fracture-related R&D	--	--	negligible, ignore
20B05	All other R&D	--	--	negligible, ignore
20C05	Environmental cleanup	--	--	negligible, ignore
20D05	All other business & professional services	--	--	negligible, ignore
21.01	Printing & Publishing	-.005	-.0025	very low, mostly capital; better W III equipment requires less inspection
21.02	Radio & TV broadcasting	-.005	-.0025	very low, all for capital; better W III equipment requires less inspection
21.03	Hotels & lodging places	--	--	negligible, ignore
21A04	Personal services	--	--	negligible, ignore
21B04	Repair services, except auto	--	--	negligible, ignore
21.05	Automobile repair & services	--	--	negligible, ignore

Sector	Title	World I	World III	Notes
21.06	Amusements	-.0025	-.0012	very low, mostly capital in relevant activities in this sector; W III better equipment reduces inspection needs
21.07	Medical & health services	--	--	negligible, ignore
21.08	Educational services & nonprofit organizations	--	--	negligible, ignore
22.01	Post Office	--	--	negligible, ignore

RATIO OF LABOR COST TO TOTAL VALUED ADDED

(A Matrix)

Sector	Ratio	Sector	Ratio	Sector	Ratio
1.01	.1322	PA15	.6132	12.01	.6208
1.02	.1322	PB15	"	12A02	"
1A02	.4591	PC15	"	12B02	"
1B03	.4591	6A01	.5881	12.03	"
1.04	.4591	6B01	"	12.04	"
2.01	.6117	6C01	"	12.05	"
2X02	.6117	6D01	"	12.06	"
2A04	.5189	6.02	"	12A07	"
2B04	.5189	6A03	"	12B07	"
2C04	.5189	6B03	"	13.01	.6226
2A05	.2152	6C03	"	13.02	.6208
2B05	.2152	6D03	"	13.03	.6208
2.06	.4447	6A04	"	14A01	.6906
2.07	.4447	6B04	"	14B01	"
3A01	.5186	7A01	.5861	14.02	"
3B01	.5186	7B01	"	14.03	"
3.02	.1593	7C01	"	14.04	"
3X03	.7442	7.03	"	14.05	"
3X05	.6129	7X04	"	15.01	.6226
3A07	.6129	8.01	.6194	15.02	.6226
3B07	.6129	8.02	"	15.03	.6226
3X08	.7108	8.03	"	16.01	.7030
4.01	.4944	8.04	"	16A02	.6323
4.02	"	8A05	"	16B02	.6323
4.03	"	8B05	"	17.01	.6735
4.04	"	8C05	"	17.02	.6096
4XA5	.6950	8.06	"	17.03	.5943
4XB5	.6950	8.07	"	17.04	.6854
4.07	.5519	9.01	.6226	17.05	.5276
4.08	.5519	9.02	"	17.06	.2573
5.01	.2781	9.03	"	17.07	.4810
5.02	.2781	10.01	"	18.01	.3742
5.03	.5003	10.02	"	18.02	.2476
5X04	"	10.03	"	18.03	.2476
5A06	"	10.04	"	18.04	.2476
5B06	"	10.05	"	19.01	.6264
5.09	"	10.06	"	19.02	"
5X10	"	10.07	"	19A03	"
5.12	"	10.08	"	19B03	"
P.07	"	11.01	.4986	19C03	"
P.08	"	11.02	.7030	19A04	"
P.13	.6132	11.03	"	19B04	"
PA14	"	11.04	"	19C04	"
PB14	"	11.05	"	19D04	"

RATIO OF LABOR COST TO TOTAL VALUED ADDED

(Continued)

Sector	Ratio
20.01	.5266
20XA2	.5451
20XB2	.1421
20A05	.5606
20B05	"
20C05	"
20D05	"
20.06	"
21.01	.6166
21.02	.5125
21.03	.5227
21A04	.5088
21B04	.4960
21.05	.4271
21.06	.5352
21.07	.6647
21.08	.8759
22.01	.8584

Scrappage Rule

(A & B Matrices)

The scrappage row rules for World II and III account for fracture related breakage (or the potential for breakage) of a column sector's "product," including that sector's work in process, or output. The rule, once applied, is intended to account for both the absolute amount of "product" thrown away and an adjustment for "product" that can be recycled. The column specific scrappage rates were determined from three sources:

(1) The data sheets prepared as a result of interviews with the column industries;

(2) Analogies suggested by the data sheets;

(3) Sector by sector review sessions with BCL industry and materials experts

A column sector's scrappage rate, once determined, is averaged out over all of the sector's input, value added, and capital. Computation of the rate is as follows:

(1) S = a scrappage rate in decimal form

(i.e., 2% rate = 0.02)*

(2) In both A & B matrices, multiply every coefficient (a or b) in the relevant column by 1-S:

$$a' = a \times (1.0 - S)$$
$$b' = b \times (1.0 - S)$$

The sector specific scrappage multipliers for output and capital for World II and III are summarized below:

WORLD II

.999:	5A06						
.9975:	3A07						
	11.03						
.995:	1.02	3X05	4.03	5.01	P.13	8.07	12.05
	3.02	3X08	4XB5	5.09	8.01	12B02	13.03
	3X03	4.02	4.08	6C01	8.06	12.03	14.03

* Note that "scrappage rate" relates to the change from W I to W's II and/or III. If the effective rate in W I is 2% of output,

$$W\ II - W\ I = -2\% = S$$
$$W\ III - W\ I = -1\% = S$$

in the above formula.

.995:	14.04	21.01					
	14.05						
	19.01						

.99:	1.01	4.07	6.02	PB14	9.02	10.05	11.05
	2A05	5.02	6A03	PA15	9.03	10.06	12.04
	2B05	5B06	6A04	PB15	10.01	10.07	12.06
	3B01	5X10	6B04	PC15	10.02	10.08	12B07
	3B07	5.12	P.08	8.02	10.03	11.01	16.01
	4.01	6D01	PA14	8.03	10.04	11.04	

.985:	4XA5
	5.03
	5X04

.98:	4.04
	6B01
	7X02
	9.01

.97:	3A01
	6B03
	7A01
	7B01
	7C01
	7.03

.94:	6D03

WORLD III

.9995:	5A06

.99875:	3A07
	11.03

.9975:	1.02	4.02	4.08	P.13	8.07	12.05	14.05
	3X03	4.03	5.01	8.01	12B02	13.03	19.01
	3X05	4XB5	5.09	8.06	12.03	14.03	21.01
	3X08						

.995:	1.01	4.07	5.12	6B04	8.03	10.04	11.04
	2A05	5.02	6D01	PA14	9.02	10.05	11.05
	2B05	5.03	6.02	PB14	9.03	10.06	12.04
	3B01	5X04	6A03	PA15	10.01	10.07	12.06
	3B07	5B06	6C03	PB15	10.02	10.08	12B07
	4.01	5X10	6A04	PC15	10.03	11.01	16.01
	4.04						

<u>.9925:</u> 3A01
4XA5

<u>.99:</u> 6B01
7X04

<u>.985:</u> 9.01

<u>.98:</u> 6B03
7A01
7B01
7C01
7.03

<u>.95:</u> 6D03

Downtime Rule

(B Matrix)

Downtime is significant in sectors which operate around the clock. In these sectors, a built-in capital redundancy is necessary to provide for standby capacity, allowing for regular maintenance and repair activity as well any downtime associated with equipment failures. In our treatment of this cost, however, allowance must be made for the fact that only a portion of the total downtime is fracture-relevant.

In making an adjustment for downtime, a convenient and consistent approach involves consideration of inspection activities requiring shutdown of equipment. However, it is not necessary always to assume that this inspection requires the complete shutdown of every 24-hour operation. We note, for example, that in the transportation sectors, there are operational or scheduled downtimes which do not affect the overall delivery of service. Hence, the time required for inspection or maintenance does not interfere with operation and does not reflect a change in the Capital/Output ratio.

Where conditions seems to require full shutdown, we adjust the Capital/Output ratio by the proportion applied to the Labor component of the Value Added (VA) coefficient. Where inspection can be accomplished without shutdown, the Capital/Output adjustment will be assumed as 25 percent of the VA Labor change; for intermediate levels of shutdown, the adjustment will be 50 percent of the VA Labor change. Just as in the case of scrappage, this factor is applied as a decrease in the Capital/Output ratios of World II.

Where increased inspection is suggested in World III, the same change ratios will be used, but will be applied as increases in Capital/Output ratios.

DOWNTIME ADJUSTMENTS TO CAPITAL/OUTPUT RATIO

SECTOR	WORLD II	WORLD III
2.01	0.9988	0.9994
2A04	0.9750	1.0350
2B04	0.9988	0.9994
2C04	1.0000	1.0000
2A05	0.9950	0.9988
2B05	0.9950	0.9988
3A01	0.9925	0.9975
3B01	0.9975	0.9988
3.02	0.9975	1.0000
3X05	0.9750	1.0000
3A07	0.9925	1.0013
3B07	0.9925	1.0013
4.07	0.9975	0.9988
5.01	0.9925	0.9975
5.03	0.9925	0.9975
5X04	0.9985	1.0000
P.07	0.9925	0.9975
P.08	0.9925	0.9988
PA15	0.9950	1.0001
PB15	0.9963	1.0000
6A01	0.9950	0.9988
6B01	0.9963	0.9988
6D01	0.9950	0.9980
7A01	019980	1.0003
7B01	0.9980	1.0003
7C01	0.9980	1.0000
7X04	0.9988	1.0000
7.03	0.9980	1.0008
18.01	0.9990	0.9995
18.02	0.9980	0.9990
18.03	0.9990	0.9995
18.04	0.9990	0.9995
21.02	0.9990	0.9995

Useful Lives/Replacement Matrices
(R Matrix)

There are no specific changes that should be made in the U-matrix in going from World I to Worlds II and III. The fracture-relevant changes in useful lives generally are taken care of by overdesign, maintenance and repair, etc. To also adjust useful lives would significantly overstate fracture costs.

This situation differs significantly from those involving corrosion and wear. These two processes continuously, remove materials from capital items that cannot be replaced easily by maintenance and repair or offset by material redundancies. In the case of fracture processes, while the weakening may be progressive, it is also localized and therefore an be discovered by inspection and eliminated by parts-substitution in the M/R procedure.

There is, however, some minor shortening of useful life that must be taken into account, even though it is too small to be handled by whole-year changes in the lower limit of the useful life range. We propose that this be accomplished by changes in the R-matrix.

The R-matrix is calculated cell-by-cell as a function of the U and G matrices. It is suggested that these two matrices be kept unchanged between World I and Worlds II and III. After the R-matrix for World I has been established, however, selected values can be adjusted to account for World II and III conditions. Conceptually, the R values are continuous fractions and can therefore be adjusted by small increments.

We proposed that, for those row-sectors which have already been established as generally fracture-relevant in use (i.e, show fracture-relevant M/R adjustements), very small changes be made to Worlds II and III. In going to World II, replacement rates should be reduced by 0.1% (i.e., multiplied by .9990); and in going to World III the reduction would be half as great (i.e., multiply by .9995).

All entries (in the R-matrix) on the following rows should be so adjusted:

9.01 Engines & turbines

9.02 General Industrial machinery & equipment

10.01 Farm machinery

10.02 Construction machinery

10.03 Mining machinery

10.04 Oil field machinery

10.05 Material handling machinery, except trucks

10.06 Industrial trucks & tractors

10.07 Metalworking machinery

10.08 Special industry machinery

11.01 Motor vehicles & parts

11.02 Aircraft & parts

11.03 Ship & boat building and repair

11.04 Locomotives, rail cars & rapid transit cars

11.05 Cycles, trailer coaches, etc.

12.01 Electrical measuring instruments

12A02 Electrical generators for powerplants

12B02 All other electric motors & generators

12.03 Industrial controls, transformers, etc.

12.05 Lighting fixtures & wiring devices

12A07 X-ray equipment

12B07 All other miscellaneous electrical machinery

13.01 Service industry machinery

13.03 Radio, TV, and communication equipment

14A01 Fracture control instruments

14B01 All other scientific instruments

14.02 Medical, surgical and dental instruments

14.03 Watches, clocks & parts

14.04 Optical & ophthalmic goods

14.05 Photographic equipment & supplies

15.01 Computing and related machines

15.02 All other office & business machines

16B02 All other miscellaneous products

19.01 Residential construction

19.02 Construction, nonresidential buildings

19A03 Construction, railroad

19B03 Construction, pipeline

19C03 Construction, other public utility

19A04 Construction, highways

19B04 Construction, bridges

19C04 Construction, dams

19D04 Construction, all other

Final Demand Changes

With the exception of the capital formation final demand column, which is treated separately, other fracture relevant final demand changes summarized below include:

- fewer non-capital purchases/replacements associated with less within scope fracture.
- maintenance/repair activities associated with consumer and social capital.
- replacement rate changes associated with consumer and social capital.
- trade and transport margins associated with (1-3) above.
- federal, state, and local payroll implications of fracture relevant inspection
- capital redundancy issues

Fewer Non-Capital Purchases

Accounted for here are those items of which less would be purchased as replacements due to less fracture within scope. Examples include container breakage and loss of contents due to e.g., bags breaking, thermal shock breakage of china/crystal in dishwashers, and use of adhesives for do-it-yourself repair of a variety of broken objects or their application as preventive measures. The rules for each of the above are applied to PCE and the three government final demand columns.

The sectors affected by fracture within scope are listed below along with their respective reductions and the rationale for each.

Sector	W II	W III	Notes
3A01	-.001	-.0005	accounts for container breakage within scope plus loss of contents
3B01	-.0005	-.00025	similar to 3A01, but lower due to smaller share of breakable containers
5A06	-.15	-.075	accounts for do-it-yourself home repair of a variety of broken objects, plus their application as preventive measures
5.09, 5X10 and 6B01	-.001	-.0005	accounts for container breakage within scope and loss of contents
5.12	-.02	-.01	includes do-it-yourself repainting associated with peeling/cracking of either the exterior or interior finish
6A01	-.20	-.10	includes do-it-yourself replacement of windows, shelves, table tops, etc.
PB14	-.005	-.0025	includes replacement of broken tiles, hoses, etc.
PC15	-.01	-.005	includes replacement of kitchenware/tableware, do-it-yourself replacement of siding and gutters, and a variety of plumbing applications, e.g., fittings, tubing, hardware
6D01	-.02	-.01	accounts for replacement of cookware, mirrors, crystal, and a variety of other finished glass products

6C03	-.02	-.01	similar to 6D01, but for china and whiteware
8.07	-.002	-.001	accounts for replacement of hand tools and a variety of household utensils.

Maintenance/Repair Activities

Considerations taken account of here include application of the five maintenance/repair rules derived for A-matrix changes to the non-capital shares of the final demands for all consumer and social capital producing sectors. For example, PCE final demand for Sector 9.01, Engines and Turbines (almost all of which consists of outboard motors in PCE), is $288 million. Of this amount, 7.4 percent ($21 million) consists of parts and factory authorized repairs (including labor). Of the $21 million, Rule #3 is applied, i.e., one percent of the $21 million is considered the fracture relevant portion. Thus, World II purchases of parts and repair services from Sector 9.01, by PCE, are reduced by $210,000.

Adjustments similar to the above are applied to the non-capital shares of final demand for all of the other social and consumer capital producing sectors. For noncapital producing sectors, rules #1, #2, and #5 are applied to each of the final demands where, for example, fracture relevant maintenance and repair services are provided by Sector 19.01 (home construction), Sector 21B04 (repair services, as for appliances), and Sector 21.05 (automobile repair).

The non-capital shares of capital producing sectors to which the maintenance/repair rules are applied are listed below:

Sector	Noncapital share (percent)
9.01	7.4
9.02	13.4
10.01	1.1
10.02	6.4
10.03	8.2
10.04	4.6
10.05	7.3
10.06	1.8
10.07	12.5
10.08	2.3
11.01	23.4*
11.02	40.1
11.03	20.0
11.04	2.4

*The noncapital share in PCE is 5 percent, as most automotive repair/maintenance is performed in Sector 21.05.

Sector	Noncapital share (percent)
11.05	10.9
12.01	1.5
12A02	2.6
12B02	28.9
12.03	16.1
12.05	83.5
12A07	26.5
12B07	42.1
13.01	11.0
13.03	6.5
14A01	38.8
14B01	11.2
14.02	15.2
14.03	100.0
14.04	4.6
14.05	30.9
15.01	5.5
15.02	4.4
16B02	28.6
19.01	20.0**
19.02	20.0
19A03	50.0
19B03	15.0
19C03	20.0
19A04	20.0
19B04	75.0
19C04	10.0
19D04	20.0

Capital Replacement

The above section described the application of the various maintenance/repair rules to the noncapital goods shares (e.g., factory authorized repair, replacement parts, etc.) of final sales by sectors producing consumer and social capital. Here, account is taken of adjustments in the replacement of the consumer and social capital stocks by the four noninvestor final demands.

The replacement adjustments are .999 for WII and .9995 for WIII times the calculated stocks of social capital on each of the following rows:

**By definition, all 19.01 activities are 100 percent maintenance/repair in PCE.

9.01	11.01	12A07	15.01
9.02	11.02	12B07	15.02
10.01	11.03	13.01	16B02
10.02	11.04	13.03	19.01
10.03	11.05	14A01	19.02
10.04	12.01	14B01	19C03
10.05	12A02	14.02	19A04
10.06	12B02	14.03	19B04
10.07	12.03	14.04	19C04
10.08	12.05	14.05	19D04

Capital stocks are calculated as follows. The purchase from a social capital producing sector (the annual purchase is the value falling in the appropriate cell in FD) in year t is equivalent to purchases for replacement plus purchases for the growth occurring between year t-1 and t.

$$\text{Annual Purchase of Social Capital}_t = \text{Replacement Purchases}_t + \text{Growth Purchases}_{t-1,t} \qquad (1)$$

The purchases for growth are equal to the stock of capital in year t-1, SK_{t-1}, multiplied by the rate of growth, g, from t-1 to t.

$$\text{Growth Purchases}_{t-1,t} = g\,(SK_{t-1}) \qquad (2)$$

As we are interested in the present stock of social capital, SK_t, (2) may be transformed by using the following equivalent for the variable SK_{t-1}:

$$SK_t = (1 + g)\,SK_{t-1} \qquad (3)$$

and

$$SK_{t-1} = SK_t/(1 + g)$$

Equation (2) may then be rewritten as

$$\text{Growth Purchases}_{t-1,t} = \frac{g\,SK_t}{1 + g}$$

The annual replacement rate of a durable good, the production of which has been growing at its long term rate of g per year and which has a replacement life of u years, may be represented as:

$$r = \frac{g}{(1 + g)^u - 1}$$

The annual replacement of social capital in year t is then equal to the stock of capital in year t multiplied by the replacement rate, r:

$$\text{Replacement Purchases}_t = SK_t \frac{g}{(1 + g)^u - 1} = (SK_t)(r)$$

Substituting equations (5) and (7) into (1) we then get

$$\text{Annual Purchase of Social Capital} = \frac{(g)(SK_t)}{(1 + g)} + (SK_t)(r)$$

As we are interested in the value of capital stock in year t, SK_t, and since the annual purchase of said capital is known (the values are those occurring in the appropriate final demand cells), we may solve for SK_t

$$SK_t = \frac{\text{Annual Purchase of Social Capital}(1 + g)}{r(1 + g) + g}$$

The use of (9) allows us to estimate the stocks of social capital held by individuals, Federal government, and state/local governments.

Trade and Transport Margins

Account is taken here of trade and transport margins associated with the above adjustments and, most important, for overall transport savings due to lighter weight materials being delivered to final demand. First, trade and transport margins associated with fewer purchases of noncapital items were calculated. Similarly, margin adjustments which account for fewer replacements were calculated.

For transport savings which result from delivery of lighter weight materials to final demand, a set of rules similar to those for the A-matrix transport changes were formulated. Generally, these rules accounted for lighter weight "hardware" going into the production of consumer and social capital for all capital producing sectors (8.01 through 16B02).

After consideration of all of the above, margin adjustments were applied as follows:

trade margins: multiply 20.01 entries in each final demand column by .997 in WII, by .9985 in WIII.

transport margins: multiply 17.01 and 17.03 entries by:

	WII	WIII
PCE	.9274	.9817
FG (defense)	.9423	.9849
FG (nondefense)	.9274	.9814
S&LG	.9258	.9814

Government Payrolls Associated With Inspection

Here, estimates of inspection activities undertaken by Federal, state, and local governments for fracture within scope were calculated and applied as payroll savings in each of the government final demands. Total savings for World II were estimated as $175 million (Federal nondefense = $115M; Federal defense = $20M; State and local government = $40M); total additional costs in World III were estimated as $175.9 million (Federal nondefense = +$115.6M; Federal defense = +$20.1M; State and local government = +$40.2M). These figures reflect payrolls associated with full time job equivalents but do not include, for example, armed forces personnel who, for example, inspect aircraft for fracture. For the above type, such personnel would be assigned other duties.

Capital Redundancy

The only capital redundancy identified in final demand was for Sector 11.02, Aircraft and Parts, in the Federal Government (Defense) column. Major causes of redundancy due to fracture include re-winging and turbine blade replacement. With respect to the former, it should be noted that the re-winging of the A-6 and C-5 fleets takes place every 15 years. Similarly, turbine blades, landing gears, helicopter rotors, etc., while examples of "life-limited" parts whose replacements create redundancies, when averaged over their respective designed lives do not result in redundancies as high as was the case for corrosion. Generally, causes of fracture-related redundancy are most sporadic and less continuous than for corrosion.

After allowances for corrosion, wear, fracture outside the scope of this project, it was estimated that three percent of the total defense aircraft fleet is inoperative as a result of fracture within scope.

INFORMATION SOURCES

The implementation of the Battelle ex ante approach requires that data be collected which relates to the technology of production of the goods and services of all sectors of the economy. Whether one is establishing the baseline data describing the industrial interactions (World I, in the context of this project), or is adjusting baseline coefficients which describe possible or hypothetical constructs (as in World II and World III), it is important that the data reflect the levels of or changes in activities, operations, or purchases that characterize the different technological states of the economy. Because of the special nature of the present project, and the intellectual processes required to conceive of and relate to the concepts of Worlds II and III, the data collection procedure required a mix of three types of information:

(1) that which would be obtained directly from industrial sources, including design or operating engineers, researchers and research management in industry, or technical staff of representative or trade associations;

(2) that from practicing researchers representing many different Battelle research sections and whose specific expertise is, or has been, applied to programs related to a number of similar industries or industrial procesess; and

(3) that from additional Battelle researchers whose broad knowledge of industries and industrial practice provided a perspective that can be generally applied across a number of sectors, and whose familiarity with, and sensitivity to, the Input/Output approach permitted estimates of coefficient changes which represented consistent and reasonable practical judgment.

As noted in the text (Chapter IV), the data collection process employed all three generic sources. Furthermore, each of these sources contributed to both row and column adjustments, i.e., representing a sector as a supplier to, or a buyer from, all other sectors. As a result of the interwoven relations among sectors, it is important to note that not all of the information pertaining to, say, Sector 7A01 (Iron and Carbon Steel), was provided by experts in the iron and steel industry. Some coefficient changes affecting Sector 7A01 resulted from discussions with experts from the gas distribution industry, from Battelle researchers with expertise in materials development and design, and from others familiar with uses of specialty steels.

The data collection procedure, as outlined in greater detail in Chapter IV, also utilized a detailed evaluation process involving a large number of researchers and other staff from the Battelle Columbus Division (BCD) research sections. These staff members, while specifically assigned to selected technical or administrative units, have both technical backgrounds and work experiences which belie the formal name of that unit. They brought to this program a wealth of experience based upon their formal backgrounds, their project work at Battelle, their outside contacts, and their research activities in other organizations.

In addition to the sources noted below, much information was obtained from members of the Advisory Board. These inputs and insights related not only to the specific organizations with which the members are, or have been, associated, but also to a broad range of activities and interests.

Principal Sources

Section	Sources
1.01	BCD Technical Economics Section
1.02	BCD Technical Economics Section
1A03	SPE*; BCD Technical Economics Section
1B03	BCD Technical Economics Section
1.04	Continental Moss Gordon, Prattsville, AL; Planters, Suffolk, VA; Del Monte, San Francisco; Kingman Fish Co., Vermillion, OH; Stokely-Van Camp, Indianapolis, IN
2.01	BCD Equipment Development Section
2X02	BCD Equipment Development Section

* SPE = Battelle Staff Project Experience

2A04 BCD Equipment Development Section

2B04 BCD Equipment Development Section

2C04 BCD Equipment Development Section

2A05 SPE; Shell Oil Company/Bellair Research Center; BCD Gas Industries Program Office; Newton Upper Falls, MA

2B05 BCD Gas Industries Program Office

2.06 Limestone plant supervisor; SIE*; BCD Glass, Coatings and Concrete Research Section

2.07 BCD Technical Economics Section

3A01 BCD Technical Economics Section; BCD Biological Sciences Department

3B01 BCD Biological Sciences Department; BCD Technical Economics Section

3.02 BCD Technical Economics Section

3X03 BCD Chemistry Department

3X05 BCD Polymer Science and Technology Research Section; BCD Technical Economics Section

3A07 BCD Physical Metallurgy and Process Metallurgy Sections; Goodyear Tire and Rubber Company; B.F. Goodrich Co.

3B07 BCD Polymer Science and Technology Research Section

3X08 BCD Polymer Science and Technology Research Section

4.01 Weyerhauser Sawmills, Seattle, WA; Syracuse University

4.02 Sword Veneer, Rock Island, IL; Stoneman Co., Oak Park, IL; American Plywood Association

4.03 Champion International Corporation, Brewster, NY; American Plywood Association, Tacoma, WA; U.S. Forest Service, Forest Products Laboratory, Madison, WI

4.04 General Box Co., Toledo, OH; Paragon Industries, Lawrence, MA

4XA5 BCD Technical Economics Section

4XB5 BCD Technical Economics Section; BCD Structural Materials and Tribology Section

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* SIE = Battelle Staff Industrial Experience

4.07 Syracuse University; Empire State Paper Research Institute

4.08 International Paper Company; St. Regis Paper Co.; International Paper Company, NY, NY; Quality Packaging Materials, Inc., Clinton, NJ; International Paper Box Machine Co., Nashua, NH.

5.01 BCD Gas Industries Program Office; BCD Energy and Chemical Processes Department

5.02 Sherex-Chemical Co., Dublin, OH; Asphalt Institute, Worthington, OH

5.03 BCD Chemistry Department

5X04 BCD Chemistry Department and Technical Economics Section

5A06 3M Company, St. Paul, MN; SPE; BCD Polymer Science and Technology Section

5B06 BCD Polymer Science and Technology Section

5.09 BCD Biological Sciences Department

5X10 BCD Chemistry and Biological Sciences Departments

5.12 SPE; Hanna Chemical Coatings Corp., Columbus, OH

P.07 BCD Polymer Science & Technology Research Section

P.08 BCD Polymer Science and Technology Section

P.13 SPE; Goodyear Tire & Rubber; Pittsburgh Plate Glass; BCD Polymer Science and Technology Section

PA14 Gates Rubber Company, Denver; B.F. Goodrich Co., Akron; BCD Polymer Science and Technology Research Section

PB14 Gates Rubber Company, Denver; B.F. Goodrich Co., Akron; BCD Polymer Science and Technology Research Section

PA15 Minnesota Gas; Plexco, Franklin Park, IL; National Transportation Safety Board, Washington; SPE, Phillips Plastics Corp., Phillips, WI; Plastic Pipe Institute, NY; DuPont; BCD Polymer Science and Technology Research Section

PB15 SPE; Nalge Co. (Div. Sybron Corp), Rochester, NY; Liqui-Box, Worthington, OH; Ethyl Corporation, Richmond, VA; BCD Polymer Science and Technology Research Section

PC15 Alma Plastics, Alma, MI; Thermowood, Dale, IN; Rotuba Plastics, Linden, NJ; Tupperware, Orlando, FL

6A01 R&D mgr (large plate glass plant); BCD industrial experience

6B01	SIE/SPE; Lancaster Glass; BCD Glass, Coatings and Concrete Research Section
6C01	Ford Motor Company; Pittsburgh Plate Glass; BCD Glass, Coatings, and Concrete Research
6D01	Lancaster Glass; SIE; BCD Glass, Coatings and Concrete Research Section
6.02	BCD Glass, Coatings and Concrete Research Section
6A03	SIE/SPE; BCD Glass, Coatings and Concrete Research Section
6B03	BCD Glass, Coatings and Concrete Research Section
6C03	SIE/SPE; BCD Glass, Coatings and Concrete Research Section
6D03	SIE; BCD Glass, Coatings and Concrete Research Section
6A04	BCD Glass, Coatings and Concrete Research Section
6B04	BCD Glass, Coatings and Concrete Research Section
7A01	ASM Metals Handbook; Forging Industry Association; Armco, Inc.; Bethelem Steel Corp.; Charles River Associates; SPE/SIE; BCD Process Metallurgy Section; BCD Iron & Steel Technology Section
7B01	ASM Metals Handbook; Forging Industry Association, Armco, Inc.; Bethelem Steel Corp.; American Iron & Steel Institute (AISI); Charles River Associates; SPE/SIE; BCD Process Metallurgy Section; BCD Iron & Steel Technology Section
7C01	ASM Metals Handbook; Forging Industry Association; Climax Moybdenum Company; Armco, Inc.; AISI; BCD Iron & Steel Technology Section
7.03	ASM Metals Handbook; Forging Industry Association; Aluminum Association, Inc.; Reynolds Metals Co.; Kaiser Aluminum; Anaconda Aluminum Co.; Private Consultant (Die Casting)
7X04	ASM Metals Handbook; Forging Industry Association; Private Consultant (Die Casting)
8.01	ASM
8.02	ASM
8.03	ASM
8.04	BCD Engineering and Manufacturing Technology Department

8A05	Armco, Inc.; Kansas University; American Association of State Highway and Transportation Officials; Lehigh University; American Board of Shipbuilders; National Association of Manufacturers; SPE/SIE
8B05	American Boiler Manufacturers' Association
8C05	SPE/SIE; BCD Engineering and Manufacturing Technology Department
8.06	Private Consultant (Die Casting)
8.07	Armco, Inc.; Private Consultant (Die Casting)
9.01	General Electric Co.; Trans World Airlines; Forging Industry Association; Private Consultant (Die Casting)
9.02	Forging Industry Association
9.03	BCD Engineering and Manufacturing Technology Department; BCD Stress Analysis and Fracture Research Section
10.01	International Harvester Company; J. I. Case Company; Forging Industry Association
10.02	Forging Industry Association
10.03	Forging Industry Association
10.04	Forging Industry Association
10.05	Forging Industry Association
10.06	Forging Industry Association
10.07	Forging Industry Association
10.08	BCD Engineering and Manufacturing Technology Department
11.01	General Motors; Society of Automotive Engineers; Society of American Body Engineers; International Harvester; J. I. Case Co.; Ford Motor Company; Structural Dynamics Research Corp.; U.S. Department of Transportation; Forging Industry Association
11.02	Boeing Aerospace; U.S. Department of Defense; The Ohio State University; Port Columbus International Airport (General Maintenance Facility); Trans World Airlines; Lockheed; Institute for Defense Analysis; Naval Air Development Center; Wright-Patterson Air Force Base (Air Force Materials Laboratory); Forging Industry Association
11.03	National Association of Manufacturers; American Boiler Manufacturers Association; American Bureau of Shipping; Society of Naval Architects and Marine Engineers; U.S. Department of Transportation; Institute for Defense Analysis

11.04	Association of American Railroads; General Electric Co.; General Motors Corp.; U.S. Department of Transportation; Forging Industry Association; Transportation Research Institute/Carnegie-Mellon University
11.05	BCD Transportation and Structures Department; BCD Manufacturing Engineering, Components and Safety Research Station
12.01	BCD Instrumentation Laboratory
12A02	Columbus & Southern Ohio Electric Company; SPE/SIE
12B02	SPE/SIE
12.03	BCD Instrumentation Laboratory; Columbus & Southern Ohio Electric Company
12.04	BCD Electronic Materials and Devices Group
12.05	BCD Electronic Materials and Devices Group
12.06	BCD Electronic Materials and Devices Group
12A07	BCD Nondestructive Evaluation and Instrumentation Group; Trans World Airlines
12B07	BCD Electronic Materials and Devices Group
13.01	BCD Instrumentation Laboratory
13.02	BCD Engineering and Manufacturing Technology Department
13.03	BCD Instrumentation Laboratory and Electronic Materials and Devices Group
14A01	BCD Physical Metallurgy and Stress Analysis and Fracture Research Sections
14B01	BCD Instrumentation Laboratory and Stress Analysis and Fracture Research Section
14.02	BCD Instrumentation Laboratory and Electronic Materials and Devices Group; BCD Nondestructive Evaluation Group
14.03	BCD Engineering and Manufacturing Technology Department
14.04	Bausch & Lomb; White-Haines; Optical Manufacturer's Association
14.05	Bausch & Lomb Inc.; BCD Chemistry Department
15.01	BCD Technical Economics Section; BCD Computer, Information Systems and Education Department

15.02	BCD Computer, Information Systems and Education Department; BCD Instrumentation Laboratory
15.03	BCD Technical Economics Section and Purchasing Department
16.01	Army Metals and Materials Research Center/Watertown Arsenal
16A02	BCD Technical Economics Section; BCD Equipment Development Section
16B02	BCD Equipment Development Section
17.01	Association of American Railroads; Automation Industries/Sperry Rail Division; U.S. Department of Transportation; Transportation Research Institute/Carnegie-Mellon University
17.02	BCD Transportation and Structures Department; National Safety Council; U.S. Department of Transportation
17.03	BCD Transportation and Structures Department
17.04	Ship Structures Committee/U.S. Coast Guard
17.05	TWA; American Airlines; Delta Airlines
17.06	SPE; BCD Gas Industries Program Office
17.07	BCD Technical Economics Section
18.01	BCD Technical Economics Section
18.02	Columbus & Southern Ohio Electric Company; former EPRI and TVA employee; SPE
18.03	BCD Gas Industries Program Office
18.04	BCD Economics Department
19.01	City of Columbus (Ohio)/Code Enforcement Division; BCD Construction Research Group
19.02	U.S. Army Construction Engineering Research Laboratory; Battelle Facilities Management Office; City of Columbus (Ohio)/Code Enforcement Division
19A03	BCD Construction Research Group
19B03	BCD Construction Research Group
19C03	BCD Construction Research Group; Columbus & Southern Ohio Electric Company
19A04	Federal Highway Administration Research Laboratories; Asphalt Institute

19B04	Franklin County (Ohio)/Engineer's Office; National Association of Counties; BCD Structural Materials and Tribology Section
19C04	BCD Construction Research Group; BCD Glass; Coatings and Concrete Section
19D04	BCD Construction Research Group
20.01	BCD Economics Department
20XA2	BCD Economics Department
20XB2	BCD Economics Department
20A05	BCD Research Management and Purchasing Departments
20B05	BCD Research Management and Purchasing Departments
20C05	BCD Environmental Program Office; BCD Energy and Chemical Processes Department
20D05	Derived as residual
20.06	BCD Economics Department
21.01	BCD Economics Department
21.02	BCD Economics Department
21.03	BCD Economics Department
21A04	BCD Economics Department
21B04	BCD Economics Department
21.05	BCD Engineering and Manufacturing Technology Department
21.06	BCD Engineering and Manufacturing Technology Department
21.07	BCD Health Care Systems Program Office and Economics Department
21.08	BCD Economics Department
22.01	BCD Economics Department

APPENDIX E. DETAILS OF THE SUPPLEMENTAL MODELS

Overview of the Methodology

Four supplemental models were used in this study: the Events Character Model (ECM), Injury Cost Model (ICM), Property Cost Model (PCM), and Environmental Degradation Model (EDM). This appendix discusses each of these models in detail, including explanations of the inputs, methodology employed, and the outputs of each model. The original proposed model structures and methodologies are presented first, followed by details of the results in a later section.

Development and implementation of the supplemental models accomplished two goals:

- An estimate of certain imputed costs associated with fracture, such as environmental degradation, pain and suffering of injury victims, nonmedical disability costs of injury, death, and cargo and other property losses.

- An estimate of "resource" costs associated with fracture, including environmental clean up costs, medical costs, health insurance administration costs, and property damage costs. These latter costs were then interfaced with the Input/Output (I/O) model results.

The overall flows among the models which achieved these goals is presented in Figure E-1. The Events Character Model determined the number of fracture related events, the average consequences of each occurrence, and the severity of their consequences. Output from this model was the number, type, and severity of fracture related human injury, death, property loss, and environmental damage consequences of events in the national economy. The Injury Cost Model estimated the dollar costs of all injury consequences. Resource costs, such as hospital and drug costs, were determined separately from imputed costs (such as death and pain and suffering costs.) Similar cost estimating procedures were employed in the Property Cost and Environmental Cost Models. Relevant cost estimates generated were then checked against I/O model results to yield the unduplicated total costs of fracture.

Conceptually, the total cost of fracture related events were measured within the following framework,

$$C = C^r + C^n$$

$$= \sum_i N_i \sum_j [(C_{1j} X I_{ij}) +$$

$$(C_{2j} X I_{ij}) + (D_i X C_{3i}) + (C_{4j} X P_{ij}) + (C_{5i} + C_{6i})]$$

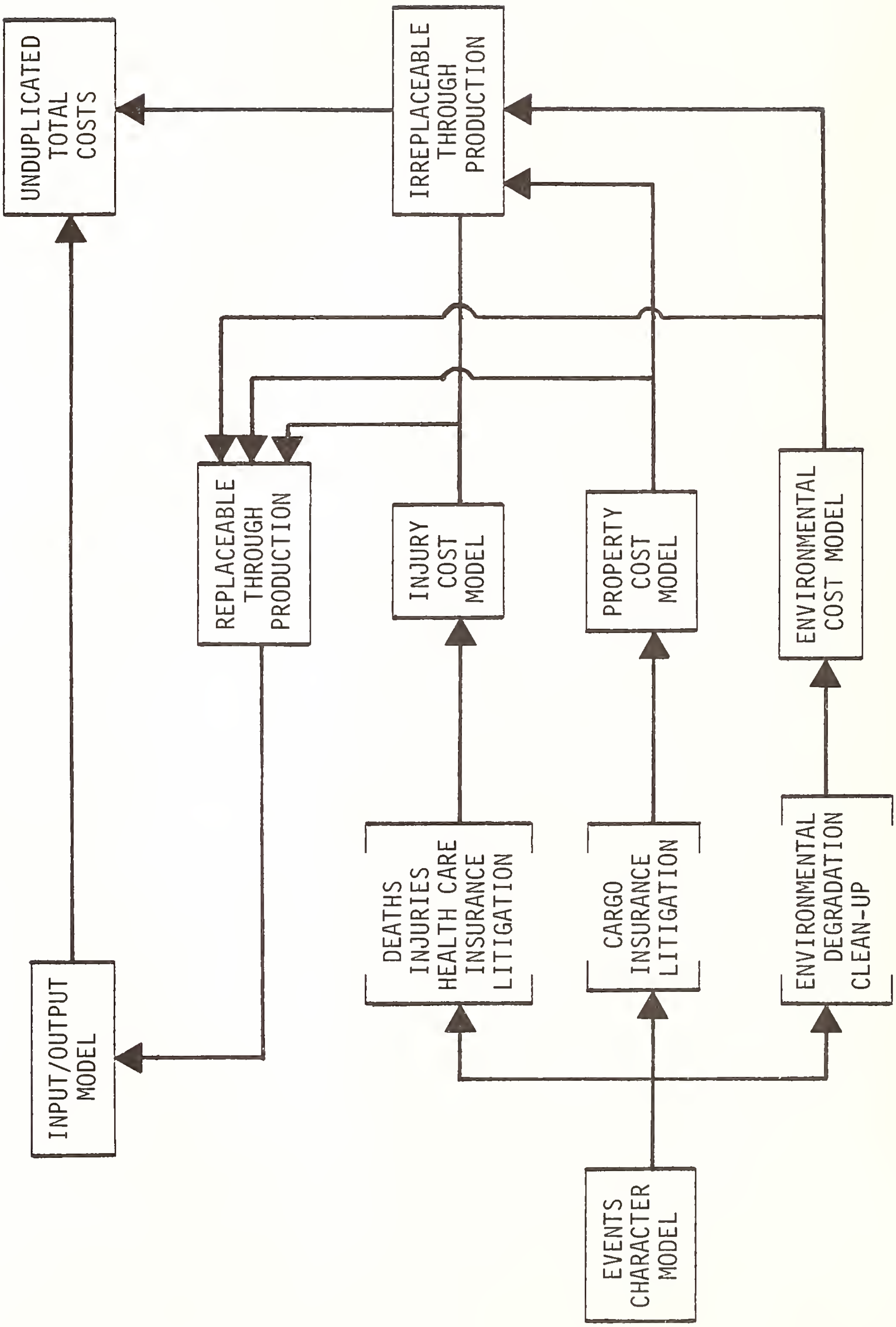

FIGURE E-1. ANALYTICAL FLOW OF THE MODELS

where C = total cost of fracture related events
C^r = resource costs
C^n = imputed costs
i = individual event categories
C_{1j} = the average injury costs that are resource replaceable for injury type j
C_{2j} = the average injury costs that are imputed for injury type j
C_{3i} = the cost of a death for each event i
C_{4j} = the average dollar value of property of type j damaged or lost
C_{5i} = the cost of environmental degradation for event i
C_{6i} = the cost of environmental clean-up for event i
I_{ij} = the average number of human injuries of type j that result from a fracture caused accident in event i
D_i = the average number of deaths that result from a fracture caused accident in event category i
P_{ij} = the average number of property items j destroyed during a fracture-caused accident in event category i
N_i = the total number of fracture caused accidents in event category i.

Each of the symbols is further explained in the following discussion. For ease of understanding, the components of the overall structure are presented in further detail below.

Events Character Model

Purpose. The Events Character Model (ECM) was designed to produce an exhaustive, nonduplicating list of nonroutine failure events that occur throughout the economy, and then determine the nature and severity of consequences of those events. The outputs of the ECM model provided the inputs for the remaining three supplemental models.

Inputs. Inputs to the ECM were fracture relevant events as drawn from Table E-1. These events may be classified into five basic types of accidents: transportation-related, work-related, home-related, public-related, and other fracture events. This list was derived in consultation with project staff from the National Bureau of Standards and other Federal government agencies.

In transportation, individual modes of transport were checked for frquency of fracture related failures. Transportation vehicles and systems resulted in a large number of accidents, many of which are due to material fracture (e.g., through fatigue associated with repetitive forces). Investigation proceeded on a modal basis as better data were available in this format.

Work related events were analyzed on an industry by industry basis, where possible. Data on the number of injuries and deaths, as well as associated property damage, were available in aggregate form for all accidents

TABLE E-1. LIST OF EVENTS

Accident Type	Events
Transportation-Related	Railroad Pipelines Auto Other motor vehicle Air Transport Marine
Work-Related	Construction Agriculture Mining Manufacturing
Home-Related	Home Product Failure Houses
Public-Related	Utilities Public Structures
Other	Military Communications-related Medical-related Storage-related Recreation-related

that occur in the workplace. Table E-1 lists examples of the fracture specific items that were investigated within each industry. Data were available for some, but not all, of these items.

Home related accident data were available for injuries that result from a large number of products used in the home. However, the number of such accidents which result primarily from fracture was not known. Thus, for this category, emphasis was placed on estimating the percentage of the accidents that result from fracture-prone products.

Public-related fractures were treated in the same way because of data limitations.

All other events were investigated in varying levels of detail. For example, military events data were available in sufficient detail to permit their use in extrapolation to related nonmilitary events. Additional information concerning the nature of all assumptions made because of data constraints is presented later in this appendix.

Methodology. ECM took the above list of events and estimated the following annual averages over a recent 3 to 5 year time period:

f_i - the frequency of accidents in the particular event category i

F_i - the fraction of f_i that is due to fracture

D_i - the average number of deaths that result from a fracture caused accident in event category i

I_{ij} - the average vector and number of human injuries of type j that result from a fracture caused accident in event category i, (e.g., within event i there may be an average of 6 broken legs, 4 concussions, and 7 severe bruises)

P_{ij} - the average number of property items j destroyed during a fracture-caused accident in event category i (e.g., within event i there may be an average of one bridge damaged and 16 automobiles lost)

E_{ij} - the average severity of environmental degradation and clean-up items j that result from a fracture-caused accident in event category i

From the list of items determined above, it can be noted that ECM is basically a tabulation model. The product of f_i and F_i yields N_i--the total number of fracture-caused accidents in each event category i. Where possible, data were obtained that estimated the severity and extent of the consequences of the average accident in N_i for each event i. Consequences that received special emphasis were the number of deaths, the type and number of human injuries, the type and extent of property damage, and any environmental degradation or clean-up costs.

Of the above, the most readily available data were the total frequency of accidents f_i, and for these accidents, information on I_{ij} (injuries) and D_i (deaths). These data were gathered from various government and private agency reports (a complete listing of references appears at the end of this Appendix). For some events, the data for element j in I_{ij} were far more detailed than for others. Generally, data in greater detail were available for the more regulated industries (railroads) than for nonregulated industries. After reviewing all available published literature, additional events data and detail were sought by contacting trade organizations, industry representatives, insurance institutes, health care facilities, and other experts.

The values of F_i, the fraction of total accidents due to fracture causes, was much more difficult to determine as there was much less information available on causes of accidents. Thus, in large part, informed judgments based on information from other events were used to determine F_i. For example, accidents or events which resulted from excessive loads (whether man-made or a natural disaster) or from human design error were eliminated as fracture relevant. Similarly, accidents caused by operator error were removed from consideration. Generally, in designing the list of events to be considered, only those accidents with some reasonable probability of having been caused by a fracture failure were included.

The data collection for P_{ij} came from reported information where available. Where no solid reported data were available, informed judgments, similar to those described above, were made for the extent of property damage for an event N_i.

As originally conceived, the final ECM data requirement was for E_{ij}, the number, types, and severity of environmental consequences of an event N_i. As very little information was obtained in this area, the EDM model was not fully developed (refer to a later section of this Appendix for details).

All the data collected was for the "average" year 1978. That is, in cases where the frequency of occurrence was low, data were collected for several recent years and averaged. All cost estimates made in these models are in 1978 dollars so as to provide compatibility with the I/O model results.

The availability of data, as noted above, varied considerably by both type of event and level of detail in the consequences which result from that event. Where detailed data were available, they were incorporated in the ECM. Where it was difficult and costly to obtain detailed estimates, more aggregate numbers were employed. In data-poor situations, maximum/minimum approaches were applied or information was transferred between events, as was the case, for example, in estimating the cost of environmental degradation.

Particular emphasis was placed on transportation events for three reasons. First, better and more detailed data were available for these sectors. Second, transport events cover a large share of the total accident costs to society. According to data from the National Safety Council (Table E-2) motor vehicle accidents alone account for much of both the total cost to

TABLE E-2. COMPARISON OF ACCIDENTS, 1978

	NUMBER OF ACCIDENTS (Millions)	COST ($ Billions)	DEATHS (Thousands)	DISABLING INJURIES (Million)
Motor Vehicle	18.3	34.3	51.5	2.0
Work	10.2	23.0	13.0	2.2
Home	27.1	7.1	23.0	3.5
Public, Recreation, Other Transportation	29.1	5.6	21.5	2.7

Source: Accident Facts, National Safety Council.

society and the cost of premature deaths among all accidents. Also, considering that transport devices are often subject to repetitious stresses and are therefore more prone to material fracture than, say, home appliances, transportation events may be quite fracture-relevant. Third, the severity of an accident in a transport industry is often greater than in many non-transport industries. Large numbers of people are affected by airline accidents, large amounts of property are put in jeopardy when trains derail, etc. Since both the frequency of an accidents caused by fracture can be higher, and their consequences generally more severe, these events received proportionately more attention than other categories.

Injury Cost Model

Purpose. The Injury Cost Model (ICM) employed herein draws primarily upon a model developed by Battelle's subcontractor Technology + Economics, Inc. (T+E), of Cambridge, Massachusetts. This model provided social cost estimates for human injuries and deaths that result from fracture relevant events. Estimates were made in 1978 dollars for both resource and imputed costs.

Input. The inputs to the ICM were the vector of deaths D_i and the matrix of human injuries I_{ij} developed by the ECM.

Methodology. The Injury Cost Model, originally developed for the Consumer Product Safety Commission, provides cost estimates associated with accidents and failures involving consumer products. The proper scope of injury cost is defined as all costs borne by society as a result of the injury, encompassing those costs incurred by the injured party, his family, his employer, and the community in which he resides, whether they be out-of-pocket expenditures or opportunity costs.

By structuring the model in terms of a mutually exclusive and exhaustive set of injury-related societal costs, T+E can ignore the whole question of who bears the cost burden and how it is distributed, whether it be the individual victim or a third party (insurance).

Total injury costs were partitioned into a set of eleven cost components, each of which was estimated separately, utilizing the best possible procedure given available data and applicable functional relationships. Estimation techniques included regression analysis (pain and suffering costs), utilization of sample means from the disaggregation of the large data bases (hospital costs and foregone earnings), and direct analytic solution (e.g., health insurance costs). In most instances, several techniques were employed. Details are provided in Appendix F.

There are three broad types of injury costs in the ICM that estimate the human injury cost of failures: those costs representing direct expenditures associated with injuries, e.g., litigation costs, visitor and victim transportation costs; foregone earnings, e.g., the opportunity cost associated with visitor and victim time spent away from normal activities because of the injury; and those nonreimbursable costs imputable only in terms of subjective social valuations of reductions in the risk of injury occurrence. Pain and suffering costs, disability costs, and valuations of loss of life comprise this third type of injury cost.

The first and second categories of costs are the resource costs also estimated by the I/O model. The third type of injury costs are imputed costs which were subsequently added to the total I/O costs.

The ICM provided dollar amounts for the following costs:

C_{1j} - the average injury costs (in terms of resources) for injury type j

C_{2j} - the average injury costs that are imputed for injury type j

C_{3i} - the cost of a death for each event i.

The value of C_{3i} could vary by event only if different average ages of death were available by event. Since this was often not the case, a constant value of C_{3i} was employed for all events. In computing C_{1j} and C_{2j}, the level of detail of I_{ij} was considered. When it was only known that an average injury occurred, the cost estimates were for the average injury only. When more detail was available, the injury cost was computed for that specific type of injury.

The total fracture relevant costs of human injury and deaths associated with an event were calculated from the following:

$$TIC_{1i} = \sum_j (C_{1j} \times I_{ij}) \times N_i$$

$$TIC_{2i} = [\sum_j (C_{2j} \times I_{ij}) + (D_i \times C_{3i})] \times N_i$$

where TIC_{1i} is the total injury cost of replaceable resources for event i

TIC_{2i} is the total imputed injury cost for event i.

The total injury and death cost of all fractures was then computed as:

$$TIC = \sum_i (TIC_{1i} + TIC_{2i}).$$

Property Cost Model

Purpose. Conceptually, the Property Cost Model (PCM) provided cost estimates (in 1978 dollars) for all the property identified as damaged in ECM. The replacement costs of houses, buildings and industrial plants (or parts of these units) represents one aspect of property damage. Another is the costs involved in replacing the contents of housing, commercial, industrial and transportation units (e.g., large cargo losses due to water damage, furniture and contents losses due to foundation failure in domestic housing units, cargo losses due to spillage from trains, trucks and marine transportation units, etc.). Also included in property damage are losses associated with the replacement of a destroyed transportation unit (barge, truck, automobile, railcar, etc.).

Input. The input given to PCM was the matrix P_{ij} of the average number and type of property damage per accident by event i and the vector N_i of the number of occurrences of the accident due to fracture. These data were often not detailed or complete, forcing estimates to be made.

Methodology. The method that was attempted to evaluate property damage costs was a simple listing of each item of property damaged j. Where severity of the damage was known, it was included in the costing of the damage.

The average dollar value of each piece of property damaged or lost is represented by C_{4j}, which indicates that the cost of each separate item needed to be obtained. For example, a totally destroyed house should have a different cost estimate than a partially destroyed house; i.e., each is represented by a different j in the P_{ij} estimate of ECM and each had a separate C_{4j} cost associated with it in this model.

The cost of property damaged by event may be calculated as

$$TPC_i = \sum_j (C_{4j} \times P_{ij}) \times N_i$$

where TPC_i is the total property cost loss associated with event i.

The total cost of all property damage was then computed as

$$TPC = \sum_i TPC_i$$

Because of data scarcity, the ability to produce detailed costs was considerably hampered. Even insurance institutes, for example, did not have cost data for specific items of property that were necessary. Where information was available, it is reported in the property damage section. Cargo losses were treated separately in that they were estimated on a sector by sector basis and treated as a Final Demand column in the I/O model.

Environmental Degradation Model

The Environmental Degradation Model (EDM) was designed to estimate:

- Environmental clean-up costs
- Direct loss environmental damages or the welfare damages of environmental degradation.

Environmental clean-up costs included the labor, material, and capital costs required to clean up environmental damages associated with failure-related incidents. Such clean-up costs included attempts to mitigate damages in air, land, and water media, and account for cross-media linkages in clean-up efforts. Also, these costs are associated with expenditures for clean-up in both the public and private sectors. To the extent possible, both private and public expenditures were accounted for in EDM. Clean-up costs were also treated as a separate row sector in the I/O analysis.

Direct loss environmental damage, or the welfare damages of environmental degradation, are more or less commensurate in dollar terms. In the abstract, welfare damages of environmental degradation are imposed directly on individuals in the form of foregone benefits without the intervening mechanism of explicit money outlays.

Purpose. EDM attempted to measure in dollar terms the environmental costs identified in the E_{ij} matrix of the ECM.

Input. The inputs to EDM were the matrix E_{ij} of the j types and severities of environmental consequences associated with fracture accidents and the vector N_i of the number of such fracture accidents by event i.

Methodology. As originally conceived, the EDM would provide cost estimates for the consequences in E_{ij} by completing the following five steps.

First, the consequences of an event i were to be listed in the corresponding vector j of the E_{ij} matrix. These would then be separated into environmental degradation consequences E_{id} and environmental clean-up consequences E_{ic}.

Second, cost weights corresponding to a consequence were to be assigned to each severity of the consequence as given in E_{id} and E_{ic}. Implicitly, this step would involve the assignment of relative costs to different severities and different consequences.

Third, all the weights assigned to the consequences of a particular event were to be added together, producing a single number for each event. This would then result in an index for each E_{id} vector and each E_{ic} vector, which would have a larger value if the environmental consequences of the event were greater.

Fourth, data concerning the environmental costs of known specific events were to be collected. A minimal amount of actual case data would then be related to the index developed in step 3, using appropriate statistics. This step would have then resulted in a functional relationship between dollar cost and each value of the index.

Finally, the above function would be used to assign a cost to each event i. Thus, by developing a severity index of the consequences of an event, a minimal amount of actual data would be necessary to calibrate EDM.

Mathematically, the above would result in the assignment of varying weights W_d and W_c to each consequence and their summation to total indices:

$$S_{id} = \sum_{d}(W_d \times E_{id})$$

$$S_{ic} = \sum_{c}(W_c \times E_{ic})$$

These indices would then be related to specific environmental cost data as follows:

$$C_{5i} = f_d(S_{id})$$

$$C_{6i} = f_c(S_{ic})$$

where C_{5i} is the cost of environmental degradation for event i
C_{6i} is the cost of environmental clean-up for event i.

The functions f_d and f_c would be obtained through regression analysis on known values of C_{5i} and C_{6i}, which were related to their corresponding index values S_{id} and S_{ic}. Once obtained, these functions would be used to assign a cost value to every event with an index value.

To calculate the actual cost of an event, the number of occurrences of the environmental event would be multiplied by the costs.

$$TEC_i = (C_{5i} + C_{6i}) \times N_i$$

where TEC_i is the total environmental cost associated with event i.

The total cost of all environmental damage would then be

$$TEC = \sum_i TEC_i$$

The above discussion was provided to indicate how we hoped the model would be developed. As it turned out, it was not reasonable to do this for one simple reason, lack of data. Among events in ECM, very little information was available on what the environmental consequences of an event caused by fracture might be. Many assumptions about most likely environmental consequences would have had to be made for each event. Once this was done, the above models could be developed which would roughly ascribe costs to these consequences. However, it was not deemed appropriate to do this series of assumptions/estimations. Instead, those known environmental consequences are discussed in more qualitative terms. A later section of this appendix provides further detail on how this was done.

Summary

The total costs from all the supplemental models was then obtained by summing

$$C = C^r + C^n = TIC + TPC + TEC$$

since each estimate is non-duplicating and in 1978 dollars. This was done separately for resource costs and imputed costs. The following section presents model results.

Results

Events Character Model

The ECM results are presented below on an event-by-event basis. In most cases, a table of information summarizing data and assumptions is provided for each event. In addition, each table includes a short discussion of how the numbers were obtained, the results of the minimum/maximum approach, and indications of where information was transferred between events.

Rail Transportation. The railroad industry is regulated to a higher degree than many industries. As a result, more accurate statistics are available on railroad accidents, their causes, and their consequences. The ECM results for the railroad industry are presented in Table E-3. In reviewing these data, it is observed that a high percentage of the accidents are attributed to fracture events. There are three major reasons for this. First, railroads are subject to regular inspection, safety checks, and--when needed--formalized accident investigations*. Second, operators are well trained and less susceptible to human errors, thus, those accidents that do occur are more likely to be a result of material failure. Third, since both the vehicle and the way (rails) are counted as accident causes, there is a possible doubling of the percent of accidents due to fracture.

It is also worth noting that even in an industry which collects detailed statistics on accidents, there was little information available on environmental degradation. As will be seen throughout this Appendix, there is a general paucity of reliable data relative to environmental degradation and its relation to fracture events.

Pipeline Transport. Information pertaining to pipeline accidents came predominately from data gathered by DOT's Office of Pipeline Safety Regulations (OPSR) and compiled by Battelle in two reports for the American Gas Association. This was supplemented by OPSR data published by DOT's Material Transportation Board in its 1979 Annual Report on Pipeline Safety, and its 1978-79 Summary Report on Liquid Pipeline Accidents.

Natural Gas Distribution Systems. With respect to accidents occurring in gas distribution lines, relevant data included the number of leaks repaired each year, their causes, and the number of fatalities, injuries and property damage resulting from the leaks. Data collected covered a period of 9 years (1970 through 1978). Yearly averages were calculated for the total number of incidents, the total number of fatalities and injuries, and the

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* A review of 147 publications (from the Railroad Accidents Reports series), analyzing the more important accidents in 1976 and 1977, indicated that 16--or almost 11 percent--were due directly to material failure.

TABLE E-3. RAILROAD TRANSPORT

Total Number of Accidents		10,362
Percent Due to Fracture*		15.1 - 36.3
Number of Accident Due to Fracture		1564 - 2192
Injuries Due to Fracture**		70 - 90
	Amputate Arm	0.2 - 0.2
	Amputate Leg	0.2 - 0.2
	Amputate Other	0.2 - 0.2
	Fracture Arm	0.4 - 0.5
	Fracture Finger	0.4 - 0.5
	Fracture Leg	0.8 - 1.0
	Fracture Toe	0.4 - 0.5
	Fracture Head	0.4 - 0.5
	Fracture Torso	1.8 - 2.3
	Bruise	28.1 - 36.2
	Sprain/Strain	27.9 - 35.9
	Laceration	7.4 - 9.6
	Burn	1.0 - 1.3
	Dislocation	0.5 - 0.8
Number of Deaths Due to Fracture		1
Property Damage		$48.3 - 59.2 million
Environmental Damage		26 - 63 cars damaged, releasing hazardous material, resulting in 2130 - 5120 people evacuated.

Source: Accident/Incident Bulletin No. 146, Federal Railroad Administration, Railroad Accident Reports, Various Tables.

* The lower bound includes accidents resulting from the failure by breaking of key vehicle or rail parts, plus some fraction (one-fourth or one-half) of accidents caused by events that might have been fracture, e.g., "Switch point worn or broken". The upper bound includes all such events as being fracture caused. Actual counts of the number of accidents were made.

** The total injuries due to fracture were determined by a percentage of the total railroad injuries (15.1 to 36.3 percent). The details provided are a normalization of injuries that occurred to this total of 70 - 90 injuries. This does not imply that a fractional number of injuries occurred in a given year, but rather, that on average these are the injuries that occur.

TABLE E-4. PIPELINE TRANSPORT

	Distribution	Transmission and Gathering	Liquid
Total Number of Accidents	1,096	448	262
Percent Caused by Fracture	3.1-7.8	4.3-10.8	3.8-30.3
Number Caused by Fracture	34-86	19-48	10-79
Fatalities due to Fracture	1-2	0-0.4	0-1.5
Injuries due to Fracture	10-24	1-2	0-3
Total Property Loss due to Fracture*	2.1-5.3	5.7-6.0	0.1-1.1
Environmental Degradation due to Fracture	--	--	12,000 to 97,000 barrels of Commodity lost.

Source: See text.

* Property damage estimates, in million of 1978 dollars, include damage to both pipeline and nonpipeline property; these estimates were based on court settlements awarded during an average year between 1970 and 1978.

amount of property damage. The percentage range of incidents due to fracture was calculated on the basis of general information on cause provided by the Gas Distribution companies, and the more detailed causal breakdown provided by Transmission and Gathering Companies. The resulting percentage range due to fracture (3.1 to 7.8 percent) was then applied to the total yearly averages to obtain the estimated numbers due to fracture (see Table E-4).

Natural Gas Transmission and Gathering Systems. Data collected on Natural Gas Transmission and Gathering Systems was extremely detailed. These data provide both a breakdown of accidents by cause, and a further breakdown of those accidents caused by material failure (15.8 percent) in terms of the origin of failure. This latter information was used to determine the upper and lower bound percentages of accidents due to fracture. A breakdown of material failure incidents with respect to their origin is provided in Table E-5.

TABLE E-5. COMPONENTS INVOLVED IN NATURAL GAS PIPELINE MATERIAL FAILURES

Origin	Percentage of Material Failure Incidents
Body of Pipe	27.2**
Girthweld	8.6*
Longitudinal weld	22.1*
Other field weld	1.1*
Compressor	1.6*
Valve	4.9*
Scraper trap	0.2
Trap connection	3.2*
Fitting	17.4
Gas Cooler	0.2
Other	13.2

* Assumed to be fracture-related upper bound. (i.e., total of 68.7 percent), such that 10.8 percent (68.7 of 15.8 percent) of all accidents could be fracture-related.

** Assumed to be fracture-related lower bound, such that 4.3 percent (27.2 of 15.8 percent) could be fracture related.

Data on fatalities, injuries, and property damage were also broken down in terms of the origin of material failure incidents. Those occurring in the appropriate upper and lower bound categories were tabulated directly and averaged over the 9 year period to provide the total number of incidents, fatalities and injuries, and the amounts of property damage due to fracture (see Table E-4). The small percentage range (4.3 to 10.8 percent) and small number of deaths and injuries due to fracture in this particular sector are noteworthy. It should also be noted that there was some discrepancy in the Transmission and Gathering Systems data provided to Battelle by OPSR (in the form of computer tapes) and that published in the 1979 Material Transportation Board's (MTB) Annual Report. Since the discrepancy has not yet been resolved with DOT, the numbers published by MTB, which on the average tended to be higher, were utilized.

Liquid Pipelines. As seen in Table E-4, the number of liquid pipeline accidents attributable to fracture and the resulting fatalities, injuries, and property damage are very small, despite an upper bound (30.3 percent) that is much higher than that for natural gas distribution and for transmission and gathering systems. Information on liquid pipeline accidents came primarily from MTB's 1979 Annual Report; information as to cause was supplied by MTB's Liquid Pipeline Accident Report Summary for 1978 and 1979. This latter report distributes the incidents occurring in 1978-1979 by cause, where the following cause categories were assumed to be fracture related: defective pipe, girth weld, repair weld, or fabrication weld; rupture or leaking seal and pump packing failure; rupture of leaking gasket; stripped or broken threads; and pipe coupling failure. The lower bound estimate of 3.8 percent was established assuming that only those incidents caused by a defective pipe were fracture-related; the upper bound estimate of 30.3 percent was established with the assumption that all the above causes, including defective pipe, could be fracture-related.

Once established, the percentage range of accidents due to fracture was applied to the nine-year average totals obtained from MTB's 1979 Annual Report in order to determine the total number of accidents, fatalities, injuries and propert damage due to fracture.

Auto Transport 'on. The data available on accidents in the auto transport sector come pre minantly from the National Safety Council (Accident Facts) and the National Hi way Traffic Safety Administration (Fatal Accident Reporting System and National Accident Sampling System). Both are somewhat general in that they do not provide statistics with breakdown by cause (see Table E-6). The percentage of automobile accidents due to fracture (0.4 percent to 0.8 percent) was derived from results obtained in an Indiana University study which analyzed the causes of traffic accidents. These data were collected at three levels of detail: examination of 13,500 police reports, 2,258 field-survey investigations, and 420 in-depth investigations. Results revealed the following percentage distribution of probable causes:

Human only	57 percent
Human and environmental	26 percent
Human and vehicular	6 percent
Human, vehicular and environmental	3 percent
Environmental only	3 percent
Vehicular only	2 percent
Vehicular and environmental	1 percent

TABLE E-6. AUTO TRANSPORT

Total Number of Accidents	18,300,000
Percent Caused by Fracture	0.4 - 0.8 (5-10 percent of 8 percent vehicular defects)
Number Caused by Fracture	70,400 - 140,800
Fatalities Due to Fracture	206 - 412
Injuries Due to Fracture	19,700 - 39,400
Total Property Loss Due to Fracture	$46.4 - 92.8 million
Total Environmental Degradation Due to Fracture	Information Not Available

Sources: National Safety Council; National Highway Traffic Safety Administration; Institute for Research on Public Safety, Indiana University (Study Conducted for U.S. Department of Transportation).

* Assumed 8 percent of all auto accidents were caused by vehicular factors, based upon results of a survey conducted by Indiana University's Institute for Research on Public Safety, and that 5-10 percent of this 8 percent were actually fracture related. This latter assumption was based on the results obtained in the pipeline accident analysis. Pipelines and autos were assumed to be similar in that both require metal manufacturing, design, and processing, and the results of failure are approximately equally visible to the public.

Human and environmental factors, a significant 86 percent, were immediately discarded as having no fracture relevance. The vehicular factors, which included predominantly brake and tire/wheel failures, were assumed to have some fracture relevance. Based upon the results above (i.e., 2 percent of accidents caused solely by vehicular factors and 12 percent caused by vehicular and at least one other factor), and discussions with industry experts, a weighted average of 8 percent was used as the percentage of highway motor vehicle accidents caused by vehicular factors. Of these 8 percent, 5 percent to 10 percent were assumed to be actually caused by fracture, resulting in a very small percentage (0.4 percent to 0.8 percent) of total highway motor vehicle accidents being attributable to fracture. This percentage range was then applied to NSC's estimates of the total number of highway accidents (18,300,000), fatalities (51,500), injuries (4,928,000)* and property damage ($34.3 billion) occurring in 1978 to determine the respective amounts due to fracture.

Highway accident statistics compiled for 1978 by NSC and NHTSA compared favorably in terms of the estimated number of fatalities and injuries. NSC's estimate on the total number of accidents, however, was more than double that of NHTSA, attributable to the fact that NHTSA's statistical sample was taken from police files and did not account for those accidents which went unreported. Estimates of property damage for motor vehicles accidents were available only from NSC. For reasons of consistency, NSC estimates were used in calculating the total number of motor vehicle accidents, fatalities and injuries, and the property damage due to fracture.

Other Motor Vehicle Transportation. Accidents involving motor carriers were analyzed separately from motor vehicle accidents as separate, more detailed data sources were available. Data used were averaged over a two-year period (1978-1979). Approximately 5.0 percent of all accidents (1,740) were found to be caused by mechanical defects, (indicating some fracture-relevance), which resulted in an average of 100 deaths, 1,360 injuries, and $21 million worth of property damage over the two-year period. Assuming, as in the case of motor vehicles, that 5 to 10 percent of the accidents caused by mechanical defects were due to fracture, this percentage range was applied to the numbers generated above in order to obtain the upper and lower bound estimates of the number of accidents, number of fatalities and injuries, and property damage due to fracture (see Table E-7).

Limited data were also provided on the number of accidents involving hazardous materials, which could contribute to environmental degradation. Applying the same percentage range (5 to 10 percent of 5.05 percent) to the total number of accidents involving hazardous materials indicated that an

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* Because NSC's 1978 estimate of total injuries included only disabling injuries, their annual average estimate for 1975-1977, which included disabling and nondisabling injuries, was used. This is larger than the number cited in Table E-2.

TABLE E-7. OTHER MOTOR VEHICLE TRANSPORT

Total Number of Accidents	34,770
Percentage due to Fracture*	.25 to .51 (5-10 percent of 5.05 percent mechanical defects)
Number Due to Fracture*	88 - 176
Number of Fatalities Due to Fracture	5 - 10
Nmber of Injuries Due to Fracture	68 - 136
Property Damage Due to Fracture	$1.0 - 2.1 million
Environmental Degradation	1 - 2 incidents involving leakage of hazardous material

Source: Federal Highway Administration.

Assumption: 5-10 percent of accidents caused by mechanical defects were fracture related. Percentage due to mechanical defects (5.05 percent) was provided by FHA; of this the percentage range (5-10 percent) assumed to be caused by fracture was based on results obtained in the pipeline accident analysis.

average of 1 to 2 incidents per year would be due to fracture. Data pertaining to the quantity or type of material involved and the affected resources were not available.

Aviation Transportation. Detailed information on aviation accidents was obtained from the National Transportation Safety Board's (NTSB) Aviation Accident tapes which are compiled annually and computer stored. Relevant information included the type of aircraft, the degree of damage to the aircraft--both qualitative (minor, substantial and destroyed) and quantitative (full damage loss), number of fatalities, injuries, and a detailed breakdown on cause. This information was compiled on an accident-by-accident basis. Accidents caused by fracture were then tabulated so as to estimate the resulting number of fatalities and injuries, as shown in Table E-8. (The establishment of upper and lower bounds was not necessary in this particular case.) With regard to the property damage estimate, two caveats should be noted: (1) the estimate includes damage to aircraft only (information on cargo losses was not available); and (2) the estimate was based upon the qualitative information provided in the tapes (quantitative information on full loss damage was incomplete). The methodology used to estimate property damage involved a breakdown of those accidents caused by fracture into three categories: those in which the aircraft was destroyed, those in which the aircraft received substantial damage, and those in which the aircraft received minor damage. Each category was then tabulated separately and multiplied by the appropriate "average cost" per aircraft. The three subtotals were then combined to give the total property damage estimate.

Marine Transportation. As seen in Table E-9, the percentage of marine accidents due to fracture is low, a not-surprising result as vessel weight is not a critical factor in design and vessels are constructed to be structurally solid. The percent due to fracture is a single value and not a range as the level of detail (with respect to cause) found in the Coast Guard data was sufficient to allow simple tabulations of the number due to fracture. The U.S. Coast Guard, through the Pollution Incident Reporting System (PIRS), compiles on a yearly basis the following types of information on marine accidents: location of accident, type of vessel involved, cause, materials involved and quantity spilled, affected resources, and cost of clean-up. Data for 1978 were analyzed and results were tabulated to determine the total number of accidents due to fracture.

Fatalities and injuries resulting from marine accidents were estimated from data in another Coast Guard Publication (Polluting Incidents in and around U.S. Waters). Data were averaged over the 9-year 1970-78 period to yield an annual average estimate of fatalities (542) and injuries (1,495) occurring during this time period. The percentage due to fracture (0.7 percent) was then applied to each of these figures to obtain estimates on the number of fatalities and injuries due to fracture.

As PIRS contained only quantity of material lost data, two other data sources were used to obtain upper and lower bound estimates on property damage. The upper bound was calculated by multiplying the total number of

TABLE E-8. AVIATION TRANSPORT

Total Number of Accidents	4,518 (4,494 general aviation; 24 air carrier)
Percent Due to Fracture	7.8[(a)]
Number Caused by Fracture*	354[(a)]
Total Fatalities Due to Fracture	66[(a)]
Total Injuries Due to Fracture	393[(a)]
Total Property Loss	$18.3-71.9 million
Total Environmental Degradation	No Information Available

Source: National Transportation Safety Board (NTSB) Aviation Accident Tapes (1978)

* Accidents caused by Material Failure and/or Fracture Fatigue were included in this count.

(a) In contrast with the data on other kinds of events (see, for example, Tables E-3, E-4, and E-7), the figures presented here represent exact counts for 1978, rather than derived estimates and averages over a three- to five-year time span. The actual airline figures for 1977 were comparable with those for 1978 (4286 accidents; 303, or 7.1 percent, due to fracture; 53 fatalities). Similarly, aside from the 273 fatalities resulting from the DC-10 crash in Chicago, the numbers of fracture-related incidents and fatalities in 1979 (270 and 73, respectively) were also comparable with those of 1978. Hence, the figures presented in the table above are reasonable estimates for non-catastrophic events.

TABLE E-9. MARINE TRANSPORT

Total Number of Accidents	4,417 (vessels)
Percent Due to Fracture*	0.7
Number of Accidents Due to Fracture	31
Number of Fatalities Due to Fracture	4
Number of Injuries Due to Fracture	10
Total Property Damage Due to Fracture	$58,000 - $53,800,000
Total Environmental Degradation Due to Fracture	4500 gallons of oil products spilled

Sources: U.S. Coast Guard; Pollution Incident Report System; NTSB Marine Accident Reports; U.S. Department of Transportation, 1978.

* Accidents caused either by a structural failure or loss (e.g., hull rupture or leak; tank rupture or leak) in which material fault was the contributing factor, or by an equipment failure (pipe rupture or leak; hose rupture or leak; manifold rupture or leak; loading arm fracture, rupture or leak; value, pump, flange, gasket or other equipment failure) in which material fault was a contributing factor were assumed to be fracture-related.

accidents due to fracture (31) by the average property damage cost resulting from a major marine accident ($1.7 million).* The lower bound estimate was calculated in a similar fashion; however in this case, the number of accidents due to fracture (31) was multiplied by the average property damage cost of a recreational boating accident ($1,870). This information was provided in a DOT publication, Transportation Safety Information Report, October-December 1978 and Annual Summary.

While PIRS data did include information on the quantity and type of material involved in marine accident spills, as well as clean-up costs, they were not sufficiently complete to use in estimating the cost of environmental degradation. The types of material spilled in accidents due to fracture were predominantly oil products; the quantity spilled in accidents caused by fracture totaled 9,500 gallons.

Work-Related Events. Only minimal data were available on fracture accidents in the workplace. This required a slightly different estimating procedure, which is described below.

Table E-2 indicates that the average annual number of accidents in the workplace is 10.2 million. Of this total, the portion that might have been caused by fracture had to be determined. The first approximation considered was use of Bureau of Labor Statistics data to establish an absolute upper bound on the fracture relative percentage. By judging what types of accidents seldom result from fracture (e.g., overexertion in the workplace) and what injury sources seldom result from fracture (e.g., steam) and then calculating the remainder, it was found that as much as 22.5 percent of all workplace accidents could possibly be caused by fracture, a figure that appears far too high when related for example, to transportation events. Generally events that are more people-oriented, such as driving, are much more likely to result in accidents caused by some form of human error. As accidents in the home, at work, or in public places are similarly people-oriented, one might expect a fracture relevant accident frequency more like that found in autos or other motor vehicles (0.4-0.8 percent and 0.25-0.51 percent, respectively).

As a second estimate, the very detailed military data on accidents (documented in a later section) were examined. The U.S. Navy data base on accidents indicated that 1.2 percent of all accidents may have been related to fracture or material failure, a figure derived from a very large sample of specific case studies. This sample includes both on-base and off-base accidents which approximately match a general work environment. Similarly, U.S. Air Force data indicated that 1.1 percent of all accidents occurring on

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* This value was obtained by averaging the property damage costs of 52 major marine accidents occurring in 1978 as reported in individual marine accident reports published by NTSB. It should be noted that the individual accident reports are available only for those accidents considered to be major, i.e., accidents involving loss of life, substantial loss of cargo, or property damage in excess of $200,000.

base may have been due to fracture. After examination of all of the above, 1.2 percent was selected as the highest reasonable upper bound. A lower bound of 0.25 percent was chosen, as this is the lowest frequency in other motor vehicles. Application of this range results in a total of between 25,000 and 122,000 accidents in the workplace resulting from fracture in an average year.

Using these same percentages and the data in Table E-2, we obtain the results on injury, death, and property damage as given in Table E-10. Note that the property damage estimate includes medical costs and foregone earnings estimates as well, not just property damage.

Construction. Within work-related accidents, some detailed information is available for particular sectors, which can be used as benchmarks. One such subgroup includes construction equipment (e.g., scaffolds, ladders, ropes, cables, and manufacturing machinery), where case history data from the Occupational Health and Safety Administration on fatal accidents were examined. Review of this data determined that, at the very most, 6-13 percent of such case histories might have been related to fracture. While many of the histories did not determine an exact accident cause, this information at least indicates that the numbers selected earlier are probably of the correct order of magnitude.

Agriculture. The National Safety Council estimates that 1,900 fatalities and 190,000 disabling injuries occur in the agriculture industry each year. Because of lack of data on the causes of these accidents, the overall work-related fracture frequencies were applied to this event (0.25-1.2 percent). This would indicate that there were 5-23 fatalities and 500-5,300 disabling injuries caused by fracture. These are probably overestimates to the extent that many farm accidents are provoked by human error, rather than material failure. These are already included as part of Table E-10, but are mentioned here to give a general idea of the size of the accident problem in agriculture.

Mining. The best source of data for the mining sector comes from the Mine Safety and Health Administration. Their investigation of accidents attempts to determine the number of injuries, deaths, and lost work time from accidents according to 21 different causes. Significantly, none of these causes is fracture, indicating it is a smaller problem than other areas which cause mine accidents (e.g., explosion or collapse of an improperly supported roof). In fact, only 1.0 percent of all injuries were assigned to "other injuries", which presumably includes fracture. Again, this agrees with the earlier work-related range of accident frequency due to fracture. Without further specific information, this event has been included in the compilation of overall work-related consequences (see Table E-10).

Manufacturing. The only specific information obtained in the manufacturing sector was a series of case histories involving manufacturing

TABLE E-10. WORK-RELATED ACCIDENTS

Total Number of Accidents	10,200,000
Percent due to Fracture*	0.25-1.2
Disabling Injuries due to Fracture	5,000-26,400
Deaths due to Fracture	32-156
Property Damage**	$57-276 million
Environmental Degradation	No information available

Source: Accident Facts, National Safety Council; Military data

*See text for explanation

**includes medical costs, foregone earning.

machinery. After reviewing 58 such accidents that resulted in fatalities, none were reported as being caused by fracture. Thus, while certain cutting tools, grinding wheels, or other machinery components do fracture, the extents of injuries, damage, etc., are not known.

Home-Related Accidents. The National Safety Council estimates that 27.1 million accidents occur annually in the home. However, most of these accidents are due to either human mistakes or neglect. Actual property which fractures is a rare event. To obtain an order of magnitude estimate, the detailed military data will again be referenced. For Air Force data, it was possible to determine that of 4,939 accidents which occurred off-base (similar to home and recreational environment), only 13 were due to material failure which may have been fracture. All 13 cases involved breaking glass, so even this is an upper bound. Utilizing the data in Table E-2 and the 0.26 percent frequency due to fracture derived above provides the estimates in Table E-11. An arbitrary lower bound of 0.01 percent was used since some fracture events do occur in the home.

No additional data on houses were available. While it is conceivable that an electrical appliance may fracture, resulting in short-circuiting and possible serious fires, no estimate is made here of the prevalence of such events. Rather, it is presumed that the all-inclusive category of home accidents includes them.

Public-Related. Two types of events are included in public-related events: public utilities and public structures. Each will be discussed in turn.

Public Utilities. Investigations in this area were directed toward obtaining and analyzing electric utility failures caused by such factors as turbine fracturing, where the major consequence would be a power failure and its associated social loss. As such failures seldom result in direct injury or death, it was assumed that a plausible range of 0 to 5 deaths and 0 to 10 injuries per year would result from electric utility fracture events. Data on property damage, as a result of such events, was similarly unavailable, but a gross assumption of $1 to $10 million was included as an order of magnitude estimate. The costs associated with this area are relatively small compared to other events.*

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* Discussions with operating companies further indicated that fracture was not a significant factor in any aspect of electric power generation and distribution. An indicator of service disruptions is the amount of power that must be purchased from the integrated power grids. Major purchases, or service disruptions and their consequences, derive far more from peak demands and storm-affected transmission losses than from factors related to fracture within scope.

TABLE E-11. HOME-RELATED ACCIDENTS

Total Number of Accidents	27,100,000
Percent due to Fracture*	0.01-0.26
Disabling Injuries due to Fracture	350-9,100
Deaths due to Fracture	2-60
Property Damage**	$0.7-18.5 million
Environmental Degradation	No information available

Source: Accident Facts, National Safety Council; Military data

*See text for explanation.

**Includes medical costs, foregone earnings.

Public Structures. This large category was originally conceived to include diverse incidents in the public sector, such as buildings fracturing, dams failing, and bridges collapsing, among others. It does not include accidents while at work in a public place, related motor vehicle accidents, or any other transportation event.

Only very incomplete data were available to estimate the consequences of such events. As a starting point, the National Safety Council estimates in Table E-2, were used. Assuming that the frequency of fracture in the home (0.01 - 0.26 percent) is relevant for public places, and structures, total estimate for deaths, injuries and property damage were obtained. We then subtracted out other transportation, recreation, storage, medical, and communication accidents, leaving net figures of 0 to 2700 injuries, no deaths, and no additional property damage unaccounted for. Overall, this residual category did not encompass any substantial costs that were not already included in the range for other events. While we recognize that these costs are not zero, they should not be recounted after already being included in previous events. The additional injuries were costed into the total to insure complete coverage.

Other Events. Several other events deserve mention to complete the universe of accidents. Military data, which have already been referred to in determining the frequency of fracture in other events, are discussed below, followed by discussions of events related to communications equipment, medical instruments, storage devices, and recreational activities. While no detailed data were available to estimate the consequences of events, they have been included for the sake of completeness.

Military. The Defense Department maintains detailed files on accidents occurring in the Army, Navy, and Air Force. Each sector searched their respective files and provided the following types of information.

The Naval Safety Center maintains files of Naval accidental property damage exceeding $300 and injuries to Navy civilian and military personnel resulting in lost time away from work. These files were searched to retrieve records of accidents caused by material failures other than those arising from either personnel error or stress beyond normal limits. Data were provided in three separate files, the Personnel Injury/Death Master Prints, the Material (Property) Damage Reports, 5102.2, and the Material Failure Reports. The first two files proved useful in that they provided a total count of accidents caused by material failure (i.e., fracture) which resulted in either personnel injury (99) or material damage (199).* Since some accidents are included in both these totals, the 199 figure is assumed to be a more meaningful estimate of the number of accidents caused by fracture.

The Department of the Army queried their Army Safety Management Information System to identify those accidents where material failures per se, in the form of fractures or ruptures under normal operating conditions were

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* Totals were for 1979.

the initial cause factor. However, as Army accident reporting for general safety data does not provide a unique means for selecting only specified material factors, additional analyses were undertaken to exclude those incidents not having any fracture-relevance. The criteria for exclusion were based on "cause" information provided in the narrative descriptions of each accident. The total number of accidents originally reported as being potentially fracture-caused was 1,800.* However, additional analysis revealed that at least 50 percent of these were not fracture-related. Where questionable, an accident was assumed to be fracture caused. Thus, the number of accidents in the Army sector which were assumed to be caused by fracture is estimated at a maximum of 900.

U.S. Air Force failure data were provided from their Headquarters Air Force Inspection and Safety Center. As with the Army and Navy data, the Air Force data provided information on the numbers of injuries and fatalities, and the amounts of property damage, as well as a narrative and description of findings. These data were also analyzed in greater depth since not all accidents included under the material failure heading were fracture related. Of the original 139** accidents categorized as related to material failure, 30 percent were excluded as having no fracture relevance. The upper bound estimate of fracture-caused accidents occurring in the Air Force sector in 1979 was thus estimated at 97.

A significant benefit derived from the military data was the ability to use the detailed results (i.e., percentages due to fracture) as a supplement to that obtained in the civilian sector, which contained only limited data on the cause of accidents occurring in the home or at work. Percentages of accidents due to fracture in the various military services were derived from the Department of Defense Consolidated Report (1979). Accident totals for all three services were broken down into two major categories: on-duty and off-duty. The off-duty totals were further subdivided between motor vehicles (private), other (including sports and recreational) and contractor; the totals are shown in Table E-12.

TABLE E-12. TOTAL REPORTED OPERATIONAL MISHAPS IN THE MILITARY

	Total Accidents	On-Duty	Off-Duty	Private Motor Vehicle	Other	Contractor
Army	20,561	16,040	4,521	1,959	2,374	188
Navy	16,048	12,892	3,156	1,800	1,333	23
Air Force	15,015	7,999	7,016	1,936	4,939	141

* Totals were for 1979.

** 1979 data.

Using the above figures and the total number of accidents caused by fracture determined previously, the percentage of military accidents due to fracture could be calculated. Results are given in Table E-13.

TABLE E-13. MAXIMUM PERCENT OF MILITARY ACCIDENTS DUE TO FRACTURE

	Total Number of Accidents	Number Due to Fracture	Percent Due to Fracture
Army	20,561	900	4.4
Navy	16,048	199	1.2
Air Force	15,015	97	0.7

Application of these percentages to the civilian home and work sectors required a further breakdown of the total number of accidents caused by fracture into the number of accidents caused by fracture which occurred while on-duty (work-related), and off-duty (home-related), specifically the off-duty/other category. Inspection of the Air Force data revealed that 13 out of the 97 fracture caused accidents occurred at home, or 0.26 percent due to fracture (13/4939, where 4,939 is the total number of accidents occurring in the off-duty/other category). The remaining accidents were assumed to be on-duty, or work-related, or 1.1 percent due to fracture.

Analysis of the Army data revealed that about 100 of the 900 accidents appeared to be "home"-related and caused by fracture; this implies that 4.2 percent was due to fracture (100/2374); the remaining accidents were assumed to be on-duty (work-related) and consequently indicated that 5.0 percent were due to fracture (800/16,040). It should be noted that at least 60 percent of the Army accidents were attributable to motor vehicle accidents. It was impossible to determine, however, which of those accidents were on-duty and which were off-duty. This, when combined with the extreme upper bound analysis performed on the Army data, results in higher percentages for this branch of the military. It was determined that the Navy and Air Force numbers were more plausible; thus they were used as described earlier.

Communications-Related. This category of events attempted to estimate societal costs of failure in communications equipment due to fracture, including such events as the failure of an entire radio tower or a part in a transmitter. Communications-related events cause only minimal injury, death, and property damage. Of more importance is the loss to society of the communications link.

No data on the frequency of such events were obtained, nor was the likelihood of failure by fracture determined. However, it was judged that the importance of operational integrity in communications equipment leads to very careful design, manufacture, installation, and inspection. Thus, the magnitude of the fracture problem in this sector would not appear to be large. In the few observed instances where tower failures have occurred, the causes (e.g., high wind loads, or improper construction) do not involve fracture within scope. Overall, the occurrence of failures due to fracture is probably very small, especially since few moving parts are involved. Furthermore, the resultant costs are even smaller (few deaths or injuries and little environmental degradation), no costs have been allocated to this event category.

Medical-related. Medical-related fracture events include failures in medical devices used with human bodies (e.g., pacemakers, implanted prostheses, or artificial organs). Failure of hospital equipment has already been included in work-related events.

As it is presumed that all medical devices are state-of-the-art and at best practice, fracture caused failures should be minimal. Pacemaker parts do fail occasionally, and the consequences are severe. When an artificial limb or organ fails, serious and costly injury may result. For the sake of completeness, 25 fatalities plus 25 injuries were assumed as the upper bound of costs for medical-related events. There was no evidence that any fracture failures do occur, thus the lower bound was set to zero. Associated property damage in such cases is relatively minor (compared to injury costs) and are assumed to be less than $100,000 annually.

Storage-Related. Storage-related events result from failure in storage tanks or vessels. Potential consequences are spilled oil and chemicals resulting in property loss, environmental degradation, and potential health hazards. The Environmental Protection Agency (EPA) monitors hazardous material spills; these account for the majority of costs in this category of events.

The EPA data were widely variable in detail by reporting region. Individual descriptions were provided for the causes and consequences of each accident that resulted in spillage of hazardous materials. A review of the data suggested that, while 93 incidents may have been fracture caused in 1978, only 19 were related to storage devices. The others involved pipelines, trucks, rail cars, etc. The exact materials spilled were determined and costed as property loss in the Property Cost Model. Few injuries and deaths were associated with these accidents. For lack of exact data, an upper bound of 19 injuries and 10 deaths were costed. Again, the lower bound for injuries was set at zero. Since environmental consequences may be large, the type and amount of materials spilled were passed to the EDM.

Recreational-Related. Some recreational items can fracture, such as skis and baseball bats. The general nature of recreational equipment and its use by individuals is reasonably comparable to events in the home and use of home appliances, commodities, etc. Because of the lack of specific detailed data, the same assumption was used as in home-related events, namely, that 0.01 percent to 0.26 percent of all accidents occur due to fracture. The total number of recreational accidents was obtained without including injuries where fracture could not be a cause (swimming, for example, was not included). Results are presented in Table E-14. Property damage and environmental degradation were assumed to be zero for this category of events.

Injury Cost Model

Given the details of injuries and deaths by event, this section now costs their consequences in 1978 dollar terms based on the T+E Injury Cost Model. First, a discussion is presented of the methodological considerations relative to model adaptation for this project. This is followed by: a discussion of the supplemental data sources used to augment the model; a description of the estimating approach including the event-specific estimates of average injury costs; and a discussion of how estimates of the value of loss of life were calculated for a number of different valuation procedures.

Methodological Considerations. The estimates of societal costs of injuries which result from material fracture-related accidents are based on the T+E Injury Cost Model. This model was originally developed for the Consumer Product Safety Commission for the purpose of estimating the costs of consumer product-related injuries. Details of this model are contained in Appendix F.

The Injury Cost Model was developed from a number of different data sources to provide estimates, on a modular basis, for eleven different cost components for any specific injury. The cost components included in the model are the following:

- Medical Costs
- Retreatment Costs
- Foregone Earnings
- Health Insurance Costs
- Product Liability Costs
- Litigation Costs
- Transportation Costs
- Visitor Foregone Earnings
- Visitor Transportation Costs
- Pain and Suffering Costs
- Disability Costs.

The model also provides estimates of the value of loss of life for a number of different valuation methodologies.

TABLE E-14. RECREATION RELATED ACCIDENTS

Total Number of Recreational Injuries	1,400,000
Total Number of Recreational Deaths	1,570
Percent due to Fracture*	0.01 - 0.26
Injuries due to Fracture	140 - 3600
Deaths due to Fracture	0 - 4

Sources: Accident Facts, National Safety Council; Military data.

* Assumed same as home-related accidents

The model generates estimates on a disaggregated basis for each of the injury cost components listed above on the basis of type of injury, body part injured, and age and sex of the victim. Furthermore, with the exception of the product liability insurance and litigation cost components,* the costs are estimated in a manner which is independent of the cause of the injury. It should be noted, however, that the structure of the model, in terms of classification of injuries and disaggregation among demographic characteristics of the victims, is designed to interface directly with the NEISS injury data base maintained by the Consumer Product Safety Commission. Estimates of total injury costs are obtained by applying injury frequency data to the model and, in effect, adding up the costs of specific injuries on the basis of these frequencies.

Before proceeding, two additional points regarding the nature of the injury cost estimates obtained from the model are relevant. First, the model provides cost estimates for acute injuries only. That is, injuries which are not severe enough to require medical care are not considered in the model. Second, for any specific type of injury, the model provides separate cost estimates depending on whether the victim is treated and released or, alternatively, hospitalized. Thus, another dimension along which the model is disaggregated involves the type of medical care received by the victim.

We turn now to the problem of adapting the Injury Cost Model for use in providing estimates of injury costs which result from accidents involving material fracture. The number of different events or types of activities in which such accidents can occur has already been provided by ECM. The problem, therefore, involves developing estimates of the average cost of an injury for any given event. These average cost measures may then be multiplied by the overall frequencies to obtain total injury costs.

The construction of average cost estimates for the set of injuries which occur in each event category requires a weighting procedure by which the disaggregated injury cost estimates produced by the model are combined to produce the average. To obtain the true average, the weights must correspond to the relative frequencies of the injuries broken down by the dimensions of the model, i.e., type of injury, body part injured, age and sex of victim, and the disposition of the case. Use of the model requires the input of injury data which specify frequencies disaggregated along the same dimensions as the model. If such data are not available, then costs along the various dimensions of the model must, by necessity, be aggregated on the basis of a **priori** assumptions regarding the relative frequencies.

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* The product liability insurance and litigation cost components of the model specifically concern injury-related costs resulting from accidents involving consumer products. While such cost concepts are relevant to material fracture-related accidents, major data limitations and the general inability to identify the share of relevant costs attributable to personal injury, as opposed to physical damage, made developing event-specific cost algorithms for these components infeasible.

During the course of this project, an extensive search of potential data sources that would be suitable for deriving relative injury frequencies for weighting purposes was conducted. This search, however, failed to reveal any data sets that provided such frequencies for injuries specifically resulting from material fracture. As an alternative, injury frequency data specific to a number of event categories were examined. These related to the frequency of different injuries stemming from a number of different causes, rather than resulting exclusively from fracture-related accidents. As no other relevant and sufficiently comprehensive data exist, these data were used under the assumption that the observed frequencies were a reasonable approximation of the frequencies of different injuries which result from fracture-related injuries. In those cases where no injury frequency data for a specific event existed, estimates were based on either an unweighted average of NEISS injury costs, or an average of the estimates obtained in event categories for which specific data existed. A discussion of these supplementary data sources follows.

Supplementary Data Sources. The search of data sources revealed several data sets which contained sufficiently comprehensive injury frequency information to be useful in deriving average injury cost estimates for the different events. These include injury data regarding motor vehicle accidents collected by the National Highway Traffic Safety Administration (NHTSA), data concerning railroad accidents collected by the Federal Railroad Administration (FRA), work-related injury data from state workman's compensation programs compiled by the Bureau of Labor Statistics (BLS) as part of its Supplemental Data System (SDS), and data regarding frequencies of consumer product related injuries contained in CPSC's NEISS data base.

These data sources permitted event-specific estimates to be derived for 10 out of the 14 event categories. The event categories and the corresponding data sources are presented in Table E-15. Additional detail was calculated for specific work-related events such as construction, mining, and manufacturing. Events for which specific data were not obtainable had few fracture-caused injuries. An average cost was used for these injuries that did occur.

Data regarding injuries resulting from motor vehicle accidents were obtained from NHTSA's National Accident Sampling System (NASS). These data (for the year 1979) permit estimates of relative injury frequencies according to type of injury for automobile accidents as well as those involving other motor vehicles.* Table E-16 contains a listing of the NASS injury classification and the relative frequencies of each type of injury.

Another source of event-specific injury frequency data concerns information regarding railroad accidents collected by the Federal Railroad Administration, Office of Safety. These data, which are derived from accident/incident reports filed by all railroads, provide tabulations of the

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* See Report on Traffic Accidents and Injuries for 1979, prepared by NHTSA for documentation regarding this data base.

TABLE E-15. EVENT CATEGORIES AND SUPPLEMENTAL DATA SOURCES

Accident Type/Event	Supplemental Data Source
Automobile	NHTSA
Other Motor Vehicles	NHTSA
Railroads	FRA
Aviation	SDS
Marine	SDS
Pipelines	SDS
Construction	SDS
Mining	SDS
Manufacturing	SDS
Home-related products	NEISS
Military	None
Work-related: Agriculture, forestry, and fishing	SDS
Public Utilities	SDS
Home-related failures: houses	None
Public-related failures: public buildings, sewer systems and highway surfaces	None
Storage-related: landfill and tanks	None
Recreation-related	None
Medical-related	None
Communications-related	SDS

TABLE E-16. RELATIVE INJURIES FREQUENCIES: MOTOR VEHICLES

	Relative Injury Frequencies		
NHTSA Injury Categories	Automobiles	Other Motor Vehicles	Corresponding NEISS Injuries
Lacerations	.165	.175	Lacerations, puncture
Contusion and Crushing	.349	.271	Crushing
Abrasions	.091	.228	Abrasions
Fractures	.053	.082	Fracture
Pain	.201	.122	Nerve Damage
Concussion	.047	.039	Concussion
Hemorrhage	.004	.002	Hemorrhage, Hematoma
Avulsion	.003	.003	Avulsion
Rupture	.002	.001	Organ Damage
Sprains	.012	.018	Sprains
Dislocations	.004	.005	Dislocation
Amputation	0	0	Amputation
Burns	.003	.003	All Burns
Asphyxia	0	0	Drowning
Other	.064	.027	Dental Injuries
N =	6581	2693	

Source: NHTSA, National Accident Sampling System.

TABLE E-17. RELATIVE INJURY FREQUENCIES

INJURY CATEGORIES / SOURCE OF INJURIES	Railroads (a)	Aviation (b) (SIC 45)	Marine (b) (SIC 44)	Pipelines (b) (SIC 46)	Construction (b) (SIC 15,16,17)	Mining (b) (SIC 10-14)	Manufacturing (b) (SIC 20-39)	Agriculture, Forestry, Fishing (b) (SIC 01-09)	Public Utilities(b) (SIC 491)	Communications (b) (SIC 40)	CORRESPONDING NEISS INJURIES
Amputations	.004	.002	.003	-----	.0002	.004	.007	.005	-----	.001	Amputations, Avulsion
Burns and Scalds	.027	.014	.028	.210	.037	.050	.037	.025	.044	.008	All Burns
Contusions and Crushing	.209[c]	.162	.167	.326	.093	.200	.134	.120	.065	.113	Concussion, Crushing, Organ Injuries, Dental Injuries
Cuts and Punctures	.156	.072	.134	.053	.192	.123	.194	.224	.170	.079	Lacerations, Punctures
Abrasions and Scratches	.029	.021	.071	-----	.072	.054	.056	.082	.040	.025	Abrasions
Fractures	.004	.083	.175	.053	.127	.146	.100	.096	.073	.126	Fractures, Dislocations
Sprains and Strains	.395	.574	.331	.364	.410	.378	.414	.420	.579	.544	Sprains
Dislocation[d]	.006	-----	-----	-----	-----	-----	-----	-----	-----	-----	
Other	.119[e]	.017	.092	-----	.064	.044	.058	.027	.028	.104	Nerve Damage, Hematoma, Hemorrhage, Drowning
N=	54,644	6,232	251	19	33,420	2,180	121,751	13,191	247	3,327	

(a) Source: Federal Railroad Administration.

(b) Source: Bureau of Labor Statistics Supplemental Data System; Data from New York and California.

(c) Listed merely as "Bruise" by FRA.

(d) Listed separately from "Fracture" by FRA; included with "Fractures" by BLS.

(e) Includes all NEISS injuries noted as corresponding to "Contusions and Crushing" and "Other".

TABLE E-18. NEISS INJURY CATEGORIES - NEISS INJURY DIAGNOSIS CODES

Diagnosis	Code
Abrasions *Use:* Contusions, abrasions	53
Allergic reaction from contact with substance *Use:* Dermatitis, conjunctivitis	74
• Allergic reaction from ingested or inhaled substance *Use:* Poisoning	68
Amputation	50
• Anoxia	65
† Aspirated foreign object	42
Avulsion	72
Bruises *(unless diagnosed as hematoma)* *Use:* Contusions, abrasions	53
Burns, chemical *(including caustic burns)*	49
Burns, electrical	46
Burns, radiation *(including all cell damage by ultraviolet rays, X-rays, microwaves, laser beams, radioactive materials, etc.)*	73
Burns, scald *(from hot liquid or steam)*	48
Burns, thermal *(from flames or hot surface)*	51
Burns, not specified	47
• Carbon monoxide "poisoning" *Use:* Anoxia	65
Concussion	52
Conjunctivitis *Use:* Dermatitis, conjunctivitis	74
Contact allergy *Use:* Dermatitis, conjunctivitis	74
Contusions, abrasions	53
Crushing	54
Dental injury	60
Dermatitis, conjunctivitis	74
Dislocation	55
• Drowning *Use:* Submersion	69
• Electric shock	67
† Foreign object *Choose among:* Aspirated foreign object Ingested foreign object	 42 41

Diagnosis	Code
Foreign substance *(solid or liquid)*	56
Fracture	57
• Gas, fume, or vapor inhalation *(excluding carbon monoxide)* *Use:* Poisoning	68
Hematoma	58
Hemorrage	66
† Ingested foreign object	41
Internal organ injury	62
Laceration	59
Muscle spasm *Use:* Strain or sprain	64
Nerve damage	61
• Poisoning	68
Pulled ligament muscle, or tendon *Use:* Strain or sprain	64
Puncture	63
• Shock, electric *Use:* Electric shock	67
• Smoke inhalation *Use:* Anoxia	65
Soft tissue injuries *Use:* Contusions, abrasions	53
Sprain *Use:* Strain or sprain	64
Steam burns *Use:* Burns, scald	48
Strain or sprain	64
• Submersion *(including drowning)*	69
Tooth loss or chipping *(unless diagnosed as fracture)* *Use:* Dental injury	60
Other injury diagnosis *(Comment required)*	71
Injury diagnosis not stated	70

TABLE E-18. NEISS INJURY CATEGORIES - NEISS BODY PART CODES (Continued)

Part of Body	Code
Abdomen	
Use: Lower trunk	79
Ankle	37
Arm	
Choose among:	
Upper arm	80
Lower arm	33
Elbow	32
Wrist	34
Back	
Choose among:	
Upper trunk	31
Lower trunk	79
Shoulder	30
Bladder	
Use: Lower trunk	79
Brain	
Use: Head	75
Buttocks	
Use: Lower trunk	79
Calf	
Use: Lower leg	36
Cheek	
Use: Face	76
Chest	
Use: Upper trunk	31
Chin	
Use: Face	76
Collarbone	
Use: Upper trunk	31
Colon	
Use: Lower trunk	79
Diaphragm	
Use: Upper trunk	31
Ear	94
Elbow	32
Esophagus	
Use: Upper trunk	31
Eyeball	77
Eyebrow	
Use: Face	76
Eyelid	
Use: Face	76
Face	76
Finger	92
Foot	83
Forearm	
Use: Lower arm	33
Forehead	
Use: Face	76
Genitals	
Use: Pubic region	38
Groin	
Use: Lower trunk	79
Hand	82
Head	75
Heart	
Use: Upper trunk	31
Hip	
Use: Lower trunk	79

TABLE E-19. INCLUDED NEISS INJURIES CATEGORIES

- Amputation
- Avulsion
- Burns, chemical
- Burns, electrical
- Burns, scald
- Burns, thermal
- Burns, not specified
- Concussion
- Contusions & Abrasions
- Crushing
- Dental injury
- Dislocation
- Drowning
- Fracture
- Hematoma
- Hemorrhage
- Internal organ injury
- Laceration
- Nerve damage
- Puncture
- Sprain

number of injuries to employees by type of injury.* The relative frequencies (for 1980) and injury classifications for this data base are presented in the first column of Table E-17. Since the reporting threshold for determining whether an accident report was required was $2,900 in physical damage costs, the data appear to be biased toward more severe injuries.

The third source of data regarding event-specific data involves workman's compensation data which are collected by states and compiled by the Bureau of Labor Statistics.** Depending on the level of detail present in the state data, the SDS data contain information regarding the incidence of different types of injuries which occur in work-related accidents according to SIC industry classification. Because of the lack of compatibility in the detail of data collected and the differences in the level of reporting coverage among different states, SDS data from the two largest states, California and New York, were combined. This provided a data base of approximately 460,000 injuries. Relative injury frequencies were then tabulated for industries relevant to specific event categories. These figures for 1978 are also presented in Tables E-17. Since both states include only those cases that exceed a minimum number of lost workdays, again, the data is biased toward more severe types of injuries.

The final data base regarding event-specific injuries concerns the NEISS data which contain information regarding injuries resulting from consumer product-related accidents and are obtained from a sampling of hospital emergency room cases. Relative injury frequencies for the relevant NEISS injuries (see Table E-17) were tabulated from the 1979 tape and used as weights in estimating average injury costs for the home-related product event.

Injury Cost Estimates. Given the above description of the supplemental data sources, we now turn to discussion of the procedure used to derive injury cost estimates for the event categories for which such data exists. The first step involved a review of the NEISS injury categories and deletion of those injury types which, in our view, were unlikely to result from fracture-related accidents. Table E-18 presents a complete listing of the NEISS injuries, while those retained for estimating purposes are shown in Table E-19.

Second, since the supplemental data provided injury frequency estimates only by injury type, simple averages (i.e., unweighted) were

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* See the Federal Railroad Administration, Accident/Incident Bulletin, No. 149, June 1981, for a description of these data.

** See Bureau of Labor Statistics, Detailed Data Available on Occupational Injuries and Illnesses, Announcement 81-1, October 1981, for documentation of the data available for the Supplemental Data System.

TABLE E-20. INJURY COSTS BY NEISS INJURY CATEGORY

NEISS INJURY CATEGORY	COST COMPONENTS											
	MEDIC	FERNS	TRANS	VFERN	VTRAN	LBLTY	HELTH	LEGAL	DSBLT	RETRT	PASUF	TOTAL
Burns	1356.44	343.18	41.38	98.26	19.75	64.58	64.80	58.69	5599.19	116.98	9759.04	17522.18
Scalds	1356.44	343.18	41.38	98.26	19.75	64.58	64.80	58.69	5599.19	116.98	9759.04	17522.18
Chemical Burns	1356.44	343.18	41.38	98.26	19.75	64.58	64.80	58.69	5599.19	116.98	9759.04	17522.18
Amputation	1525.67	433.03	53.79	105.41	21.42	201.53	65.32	204.47	39714.34	583.78	19549.34	62457.73
Hot Burns	1356.44	343.18	41.38	98.26	19.75	64.58	64.80	58.69	5599.19	116.98	9759.04	17522.18
Concussion	537.46	992.12	43.81	292.10	64.98	46.64	62.26	39.59	--	--	9736.73	11815.69
Contusions	478.12	551.30	19.44	121.57	25.19	19.76	62.07	10.98	--	--	1591.29	2879.72
Crushing	419.68	553.34	50.45	121.99	25.29	68.13	61.89	62.47	--	--	17221.61	18584.74
Dislocation	929.00	956.51	26.58	213.35	46.61	27.13	63.47	18.82	--	127.30	3106.41	5515.19
Fracture	968.53	1302.65	30.75	352.56	79.09	32.09	63.59	24.10	401.56	302.58	3913.49	7470.97
Hematoma	416.09	553.62	32.42	121.99	25.29	29.49	61.88	21.34	--	--	4777.52	6039.60
Laceration	691.47	397.42	28.53	95.17	19.03	31.34	62.74	23.31	2263.70	108.68	2995.09	6716.42
Dental Injury	405.67	428.96	13.41	104.14	21.12	15.34	61.85	6.27	--	--	366.38	1423.14
Nerve Damage	773.06	1163.42	40.01	304.99	67.99	50.04	62.99	43.21	1864.81	39.81	8565.33	12975.60
Organ Injury	1669.62	1195.79	33.68	296.92	66.10	41.06	65.77	33.65	--	212.57	6613.27	10228.44
Puncture	710.98	397.42	28.08	95.17	19.03	34.39	62.80	26.55	2772.80	102.58	3451.30	7701.08
Strain	477.21	514.55	16.52	109.77	22.44	16.87	62.07	7.90	37.34	84.01	662.40	2011.08
Hemorrhage	1872.38	911.65	34.75	222.94	48.84	39.01	66.40	31.47	--	122.10	6032.04	9381.57
Submersion	862.34	577.75	59.17	160.39	34.25	84.76	63.27	80.17	--	--	22107.23	24029.30
Avulsion	791.39	397.42	28.71	95.17	19.03	33.63	63.05	25.74	2840.78	125.05	3054.86	7474.80
Average Burns	1356.44	343.18	41.38	98.26	19.75	64.58	64.80	58.69	5599.19	116.98	9759.04	17522.18
Overall Average	875.59	686.48	34.21	171.29	36.79	49.16	63.31	42.28	3264.38	113.26	7264.90	12601.59

Legend:

MEDIC = Medical Costs
FERNS = Foregone Earnings
TRANS = Transportation Costs
VFERN = Visitors' Foregone Earnings
VTRAN = Visitors' Transportation Costs
LBLTY = Product Liability Costs
HELTH = Health Insurance Costs
LEGAL = Litigation Costs
DSBLT = Disability Costs
RETRT = Retreatment Costs
PASUF = Pain and Suffering Costs

TABLE E-21. AVERAGE INJURY COST BY EVENT CATEGORY

EVENT CATEGORY	COST COMPONENTS											
	MEDIC	FERNS	TRANS	VFERN	VTRAN	LBLTY	HELTH	LEGAL	OSBLT	RETRT	PASUF	TOTAL
Agriculture	644.96	586.19	24.23	137.44	28.89	27.62	62.53	19.35	858.01	91.75	3066.30	5547.27
Aviation	627.95	621.05	23.69	145.08	30.67	26.65	62.54	18.32	373.93	87.54	3217.45	5234.86
Communication	646.20	643.51	24.01	150.91	32.03	26.75	62.60	18.42	359.11	92.63	3223.69	5279.88
Construction	668.92	608.22	24.74	143.54	30.33	28.06	62.38	19.86	765.58	93.95	3266.92	5712.49
Electric Service	620.33	559.06	22.53	128.50	26.81	25.35	62.46	16.94	723.81	92.02	2522.64	4800.45
Manufacturing	636.98	582.39	23.84	137.65	29.10	27.68	59.54	19.91	781.33	87.76	3357.12	5743.29
Marine	710.22	677.36	26.67	162.96	34.84	30.56	62.85	22.46	648.45	96.51	4056.57	6529.45
Mining	698.22	650.68	26.09	156.06	33.24	30.30	62.70	22.21	738.76	95.81	3931.62	6445.69
Pipelines	793.16	598.67	29.24	147.07	31.12	36.97	63.41	29.23	1333.54	89.46	5413.36	8565.24
NTSHA: Autos	586.42	704.23	37.43	173.93	37.41	46.56	62.43	39.50	799.08	44.79	9156.50	11688.29
NTSHA: Other	582.16	674.52	34.34	164.53	35.22	41.68	62.19	34.35	691.09	52.06	7743.10	10115.24
Railroads	630.60	605.11	22.73	142.46	30.06	25.10	62.55	16.66	709.32	86.79	2393.75	4725.12
Household	661.95	574.66	25.40	138.39	29.11	28.28	62.65	20.05	1269.93	98.50	2856.52	5765.45
Average	654.47	621.97	26.53	148.35	31.45	30.89	62.37	22.87	773.23	85.35	4169.65	6627.13

Legend:

MEDIC = Medical Costs
FERNS = Foregone Earnings
TRANS = Transportation Costs
VFERN = Visitors' Foregone Earnings
VTRAN = Visitors' Transportation Costs
LBLTY = Product Liability Costs
HELTH = Health Insurance Costs
LEGAL = Litigation Costs
OSBLT = Oisability Costs
RETRT = Retreatment Costs
PASUF = Pain and Suffering Costs

constructed for each NEISS injury class.* This involves averaging over the body part injured, the age and sex of the victim, and the disposition of the case. Since each injury is costed separately for treated and released, as well as hospitalized, victims, the simple averages reflect an implicit assumption that approximately one-half of the cases are hospitalized. These averages were produced for three age groups (0 to 20, 20 to 64, and 65 and over) as well as for all ages. These estimates are presented in Table E-20 with the averages for all included injury classes.

The final step involved utilizing the relative injury frequencies derived from the supplementary data to produce weighted averages for the NEISS injury cost estimates for each event for which specific injury frequency data existed. In the cases where a one-to-one correspondence did not exist between the injury categories in the supplemental data and the NEISS injury classes, it was assumed that the relevant weight was divided equally among the associated NEISS Injuries (see Table E-16 and E-17). The estimates of event-specific weighted average costs appear in Table E-21.

Valuation of Loss of Life. In addition to the estimates of the social costs of non-fatal injuries, the model also provides for the valuation of loss of life in the case of fatal injuries. Estimates of the value of loss of life under six different methodological approaches are included, broken down by age and sex of the victim. These procedures are based on the human capital approach, quality-adjusted life-years, and the "willingness to pay" approach, and include adjustments to reflect the societal value of loss of life.

A complete discussion and documentation of the loss of life estimates are presented in Appendix G. After review, a range of costs across all ages and both sexes was established at $200,000 to $600,000 per premature accidental death. A single range was chosen because the age distribution of individuals involved in fracture accidents was not known.

Summary. The information contained in Table E-21 was used to cost out the injuries identified by the ECM. Average costs were used for events where more specific detail was not available. Separate cost multiplications were performed for both resource and imputed costs in the final results. Each death was costed at $200,000 to $600,000.

Resource costs were between $44.7 and $132.8 million, while imputed costs ranged between $223.2 and $570.6 million (plus $63.4 - $454.3 million for the cost of fatalities). Note that most of these costs result from auto, work, and home-related events because of the large number of accidents that occur here.

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* For example, as all the included types of burns have the same costs, they are treated as one injury class for averaging purposes.

TABLE E-22. PROPERTY DAMAGE BY EVENT FROM ECM

Rail	$48.3 - 59.2
Pipeline	$8.0 - 12.5
Auto	$46.4 - 92.8
Other Motor Vehicle	$1.0 - 2.1
Aviation	$18.3 - 71.9
Marine	$0.1 - 53.8
Work-Related*	$57.0 - 276.0
Home-Related*	$0.7 - 18.5
Public Utilities	$1.0 - 10.0
Public Structures**	$0.0
Communications-Related	$0.0
Medical-Related	$0.0 - 0.1
Storage-Related	$3.0
Recreational-Related	$0.0 - 0.1
Total	$183.8 - 600.0

Source: Synopsis of ECM Section Tables.

* Included medical costs and foregone earnings of industries, thus overestimating property damage substantially.

** While it is recognized that this residual category cost is a positive number, the other events have already incorporated all recognizable costs which might have been attributable to public structures.

Property Cost Model

As mentioned in the methodological introduction to this appendix, much of the envisaged property cost model could not be developed in detail because of insufficient detail available in the ECM concerning specific items of property destroyed or damaged in a fracture-caused event. Again, two types of property costs were examined: resource and imputed costs.

An overview of the data provided by ECM is shown in Table E-22. As explained earlier, total property loss estimates were often made in aggregate form without specific items of property being listed. Rather than attempt to cost out a vector of assumed property damages, some generalizations, aggregations, and assumptions were made. Again, it is important to point out that the method used to estimate the home and work categories included medical costs and foregone earnings in the property damage estimates. Thus, these ranges tend to overstate property damage.

The total property damage range as indicated in Table E-22 is $183.8 to $600.0 million. This range allows for only rough comparison with the other cost components. As resource costs are already included in the I/O model, they are not added to the I/O results.

Imputed costs, especially the portion for cargo losses, are examined more closely. Most transportation events have some cargo loss. Thus, a sector-by-sector estimating procedure was employed, where data permitted. For pipelines, separate estimates of the size and number of spills for crude oil, gasoline, LPG, and chemicals were made from EPA data and costed using 1978 product values. EPA data also indicated that, because of fracture events, an additional $3 million of hazardous materials were lost each year from storage tanks, rail cars, trucks, etc.* For the rail sector, it was assumed that about one-fourth of total property damage observed was cargo loss, the rest being damage to the rolling stock, as rail cars often break due to fracture (hitch, flange, etc.), but no cargo is lost.

To obtain an upper bound estimate for aircraft, it was assumed that the average incident resulted in $5,000 in cargo loss (because most air accidents involved small private craft where cargo losses are minimal). This figure was multiplied by the number of air accidents due to fracture.

For automobiles, which carry little cargo relative to the worth of the vehicle, only one percent of auto property damage is assumed to be cargo loss. For trucks, one percent was also used because much truck cargo is either partially damaged or totally reusable, even when the truck itself may sustain extensive damage.

Marine data indicated that 9,500 gallons of oil were lost per fracture-caused event. Additionally, it was assumed that two percent of

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* This estimate was made assuming that the frequency of fracture occurrence among all accidents and the percentage of total spills caused by fracture were the same in each relevant event.

property damage to ships is lost property because many boats are damaged but do not sink (thus no property loss) when an accident occurs. All other events were assumed to not have significant associated cargo losses.

The above assumptions were used, together with the data in Table E-22, to obtain a total cargo loss range of $22.2 to $28.2 million. Where the nature of the cargo loss was known, such as oil, it was directly assigned to the appropriate I/O sector. Where it was not known, the remaining losses were apportioned according to the share of total output in the economy of all sectors that produce transportable commodities. The resulting final demand column may be reviewed in Appendix H.

Total property damage is approximately $183 to $600 million, of which $22.2 - $28.2 million is cargo losses. While the concept and approach in this supplemental model is straightforward, the general lack of detailed information prevented much of the desired cross-checking between the I/O model changes and the output of the PCM.

Environmental Degradation Model

As previously noted, the originally conceived five-step approach for developing the environmental degradation model was determined to be too detailed for the level of data produced by the ECM. Information that was obtained is reviewed in Table E-23.

Environmental clean-up from accidents is treated as a separate sector of the I/O table. The column coefficients which quantify average clean-up production processes from all types of spills and accidents, were obtained by an iterative ex ante process. The row coefficients were determined by reviewing the information in Table E-23 and augmenting it with inputs from other expert judgments. The values selected appear in the I/O tables. (Appendix H). Thus environmental clean-up is viewed as part of the production process of several industries, notably the oil, chemical, and transportation sectors.

Environmental degradation costs pose a different problem as they represent imputed costs to society which must be added to the I/O results.

In reviewing the information in Table E-23, it is observed that the major environmental hazard for which data are available is the leakage or spillage of hazardous and other materials. To the extent that the clean-up costs remove this pollution, the environmental degradation is mitigated. Collection of this data by different groups indicates that it is among the most costly of the potential degradation events caused by fracture.

Other known degrading events are solid waste refuse generated by wreckage of rail cars, autos, airplanes, barges, etc. Such wreckage is almost always removed thereby not resulting in a long range pollution problem. Concerning the potential for nuclear waste releases from any source, no qualifying events occurred for "average" 1978. For all other home, work, and recreation events, the types of incidents that result from fracture do not have large environmentally degrading consequences.

TABLE E-23. ENVIRONMENTAL CONSEQUENCES BY EVENT

Rail	26-63 cars damaged that released hazardous material, resulting in 2100 - 5100 people being evacuated.
Pipeline	12,000 - 97,000 barrels of crude oil, gasoline, LPG, chemicals spilled
Other Motor Vehicle	1 - 2 incidents involving hazardous materials leakage
Marine	9500 gallons of oil spilled
Storage-Related	56,000 gallons of oil, chemicals, hazardous materials leakage

There is no universally accepted procedure for estimation of degradation costs and none that can include all factors (e.g., costs of inconvenience, foregone earnings, and other imputed costs). The only solid information available is on spills (from different sources); thus, it was determined that a full scale environmental model which addresses indirect issues would not be cost effective. Instead, it was judgmentally determined that between 1 and 6 million gallons of liquids were released into the environment from fracture events (see Table E-23). Further assuming a degradation cost associated with spillage of a gallon of chemicals, oil, or other material between ten cents and five dollars, a total cost range of $0.1 to $30.0 million for this factor results. If leaked gases plus solid wastes had an equal magnitude of degradation cost, the total range would be $0.2 to $60.0 million. Overall, it is concluded that fracture relevant degradation costs, while important, do not result in massive dollar consequences.

Reliability

As has been repeatedly mentioned, data limitations for the Supplemental Models increased the necessity of making assumptions, thereby reducing accuracy. Use of the minimum/maximum approach, which placed upper and lower ranges on the data, most likely included all reasonable fracture costs. As such, the resultant ranges are deemed to be reliable. The most critical estimates were those associated with determining the fracture relevant proportions of events. It is conceivable that additional investigative efforts by the cognigant Federal, state, or local government officials, or private sector industries and associations, could result in a more detailed and reliable assignment of cause to a variety of events. This would, of course, improve the utility of the approach developed here.

However, given the combined judgemental, quantitative, and semiquantitative inputs to the calculations, the results are most likely representative of the maximum costs that fall within the scope of the program.

Total Costs

All the information calculated above is now reduced into two tables.

World I

All costs mentioned so far are for World I, the real world. They are summarized in Table E-24.

World II

By definition, World II contains no fracture events which are within the scope of this program. Thus all F_i, the proportion of events related to fracture within scope, are zero and costs are zero in all categories. It

TABLE E-24. SUPPLEMENTAL MODEL RESULTS FOR WORLD I MINUS WORLD II DIFFERENCES (Millions of 1978 Dollars)

	Resource Costs	Imputed Costs
Injuries	$44.7 - 132.8	$223.2 - 570.6
Deaths	0	$63.4 - 454.3
Property	$183.8 - 600.0	$22.2 - 28.2
Environmental	*	$0.2 - 60.0
Total	$228.5 - 732.8	$309.0 - 1,113.1

Source: Derived from Text.

* See Environmental Clean-up Sector in I/O Model.

follows that the numbers in Table E-24 represent the difference between World I and World II.

World III

World III is a World where best fracture-control practice is carried out consistently. Calculation of the difference between Worlds I and III required establishing best judgments as to the extent to which best fracture control practices are already followed. Results are presented in Table E-25 for each event. Note that the airline industry has been defined as at best practice, thus it has a value of 100 percent. The remaining events were determined to be between 70 and 100 percent of present best practice. Considerations taken into account in establishing degree of current best practice included:

- What is the potential for a product liability suit initiated by an injury, death or malfunction? Consideration of this question is an indication of the degree to which a product might be better engineered and manufactured.

- How much inconvenience would a fracture event cause to the general public? Public utilities, for example, may presently perform at more nearly best practice to avoid such inconveniences.

- To what degree is the event associated with a regulated industry? Consideration of this question might indicate that a greater degree of best practice is followed in World I, if for no other reason that to reduce potential for fines and other legal actions.

Having identified these factors, values were assigned to each category to produce the World I minus World III difference table (Table E-26). The results indicate that most of the costs incurred in the real world would also be incurred in the best practice world.

TABLE E-25. FRACTION OF BEST PRACTICE ALREADY BEING PRACTICED IN WORLD I

Rail	.80
Pipeline	.90
Auto	.90
Other Motor Vehicle	.95
Aviation	1.00
Marine	.90
Work Related	.90
Home Related	.70
Public Utilities	.98
Public Structures	.95
Communication-Related	.99
Medical Related	1.00
Storage-Related	.98
Recreational-Related	.80

TABLE E-26. SUPPLEMENTAL MODEL RESULTS FOR WORLD I MINUS WORLD III DIFFERENCES (Millions of 1978 Dollars)

	Resource Costs	Imputed Costs
Injuries	$4.5 - 17.0	$22.5 - 65.2
Deaths	0	$5.1 - 51.5
Property	$21.2 - 61.3	$3.40 - 4.10
Environmental	*	$0.02 - 6.0
Total	$25.7 - 78.3	$31.0 - 126.8

Source: Derived from Text.

* See Environmental Clean-Up Sector in I/O Model.

References

Motor Vehicles

1975 Societal Costs of Motor Vehicle Accidents, U.S. DOT, NHTSA, Planning and Evaluation, Dec. 1976, (Barbara Moyer Faigin). Costs are presented by fatality, by injury (by 6 severity levels), and by property-damage-only involvement (i.e., per vehicle). Costs included are medical, funeral, legal and court, insurance administration, accident investigation, losses to other, vehicle damage, and traffic delay. Data are for 1975 and presently no update is planned.

Transportation Safety Information Report and Annual Summary, U.S. DOT, March 1979, (Transportation Information Division). Reports and compares figures for transportation fatalities, accidents, and injuries for 1978 and 1977.

Tri-Level Study of the Causes of Traffic Accidents: Final Report, Vol. 1, U.S. DOT, NHTSA, May 1979, (Institute for Research in Public Safety), Indiana University. Presents data on traffic accident causes, i.e., vehicle defects, maintenance and inspection, etc. for Monroe County, Indiana. Determined the relative frequency of these factors and their causal contribution within a defined accident and driving population. Data collected for 1970-1974.

1978-79 Accidents of Motor Carriers of Property, U.S. DOT, FHA, Oct. 1978, (Bureau of Motor Carrier Safety). Statistics for number of accidents, fatalities, injuries, and of property damage by mechanical defects.

Report on Traffic Accidents and Injuries for 1979, U.S. DOT, NHTSA, National Center for Statistical Analysis. Presents data on motor vehicle accidents and their cause; also contains detailed statistics on injuries. Data collected through the National Accident Sampling System and limited to those accidents recorded in police files.

Highway Accident Reports - Brief Format, NTSB (for accidents occurring in 1977, 1978, and 1979). Publications contain briefs of selected highway accident investigations conducted during 1978; brief formats present basic facts (deaths, injuries, property loss), conditions, circumstances and probable cause(s) for each accident.

Railroads

Accident/Incident Bulletin, No. 146, U.S. DOT, FHA, August, 1978 (Office of Safety). Data are available for number of train and rapid transit accidents and damages by mechanical and electrical failures and track, roadbed and structures (Table 140). Fatalities, nonfatal casualties by cause (Table 104). Nature of injury (i.e., amputations - part of body; fractures - part of body; other - 8 categories) by train accidents, incidents and nontrain incidents. (Table 143).

Air Transport

Annual Review of Aircraft Accident Data, U.S. General Aviation, National Transportation Safety Board, 1978, (Bureau of Technology). Data are presented for number of accidents by aircraft type and by kind of flying, by injury index and severity of damage (pp. 25, 26). Number of accidents by injury index and severity of damage, by cause (pp. 26-29). Number of fatal, nonfatal accidents by cause/factor - detailed (pp. 40-46).

Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, National Transportation Safety Board, 1978, (Bureau of Technology). Data are presented for number of accidents for all operations by injury index and severity of damage (p. 3). Number of accidents by injury index and severity of damage by cause (pp. 52-55). Number of fatal, nonfatal accidents by cause factor detailed (pp. 64-66).

Evaluation of Safety Programs with Respect to the Causes, U.S. DOT, Federal Aviation Administration, February, 1979, (Battelle Columbus Division). Data are presented for costs by cause/factor by year (1964-1976). Number of accidents by injury index and by type of accident. These data are for air carriers.

Evaluation of Safety Programs with Respect to the Causes of General Aviation Accidents, 2 volumes, U.S. DOT, Federal Aviation Administration, Nov. 1979, (Battelle Columbus Division). Data are presented for 1971-1977 for total accidents by cause factor and injury index. Costs can be broken out by year by cause/factor.

Battelle Columbus Division 1978 NTSB computer tapes on aviation accidents. Tapes contain detailed information on an accident-by-accident basis (general aviation and air carrier operations). Information includes location, type of aircraft(s) involved, extent of damage (qualitative and quantitative in terms of hull damage loss), probable cause(s), probable factor(s), number of injuries/fatalities, and flight purpose.

Personal Communication: David Kelley, Aviation Accident Division, National Transportation Safety Board.

Marine

Proceeding of the Marine Safety Council, U.S. DOT, United States Coast Guard, (Commandant, USCG). Monthly. Included in this publication are statistical summaries of casualties to commercial vessels and statistical summary of deaths/injuries due to a vessel casualty for material failure.

Polluting Incidents In and Around U.S. Waters, 1978 and 1979, U.S. DOT, U.S. Coast Guard. A statistical summary of information provided in the Coast Guard's Pollution Incident Reporting System (PIRS).

Pollution Incident Reporting System, 1978. A computerized data base designed for the collection and maintenance of discharge data on all U.S. reported spills (oil and other hazardous substances) for 1978. Data included the spill size (gallons), type of material, source, cause, cost of clean-up, and affected resources.

Marine Accident Reports - Summary Format, January-June 1978. Publication contains a detailed narrative account of individual marine accidents, including information pertaining to the nature of the accident, cause, extent of property damage (qualitative and quantitative), and the number of fatalities and injuries.

Pipelines

An Analysis of Reportable Incidents for Natural Gas Transmission and Gathering Lines 1970-1978, American Gas Association, Sept. 1980, (Battelle Columbus Division). Number of fatalities and injuries by year. Costs by five cause categories.

Analysis of the Office of Pipeline Safety Operations 1970-1978 Reportable Incident Data for Natural Gas Distribution, American Gas Association, Oct. 1980, (Battelle Columbus Division). Data are presented for the number of fatalities and injuries by year by type of material. In addition, the number of fatalities and injuries caused by leaks and ruptures is also presented. Estimates of cost of damages are included.

Annual Report Data for Natural Gas Distribution Companies 1970-1978, American Gas Association, Oct. 1980, (Battelle Columbus Division). Number of fatalities and injuries and cost of damage resulting from leaks by year.

Liquid Pipeline Accident Report Summary, U.S. DOT, Transportation Safety Center, (unpublished). Number of fatalities and injuries by cause. Also property damage data for liquid pipelines.

Pipeline Accident Reports - Brief Format, NTSB, 1979. Contains briefs of selected pipeline accidents occurring during 1976-79. Format presents basic facts, conditions, probable cause(s), and losses for each accident in terms of the number of deaths, injuries and property damage (to pipeline and non-pipeline property).

Natural Gas Pipeline Statistics - Annual Report for 1978. Prepared for DOT, Material Transportation Board by Research Special Programs Administration, Transportation Information Center, Cambridge, MA, April 1980. Contains a wide range of safety and operational data involving the transportation of natural gas by pipeline; includes information such as the miles of pipeline installed, retired, inspected and in service, the number of leaks repaired by cause, and the number of personal injuries and the amount of property damage for the years 1970-1978.

Work Related

Occupational Injuries and Illnesses in the United States by Industry, 1975 and 1978, U.S. Dept. of Labor, Bureau of Labor Statistics. Data are presented for the private sector on number of fatalities and injuries by eight broad industry categories. Number of injuries are also available by 2 digit SIC.

Occupational Fatalities Related (4 industries) as Found in Reports of OSHA Fatality/Catastrophe Investigations, U.S. Dept. of Labor, OSHA, 1978 and 1979. The industries covered are Fixed Machinery, Roofs, Ceilings and Floors, Scaffolds, and Ladders. The data presented are number of fatalities by type of incident and by cause.

Injury Experience in (5 mining industries), 1978, U.S. Dept. of Labor, Mine Safety and Health Administration, 197. The mining industries covered are Coal, Sand and Gravel, Metallic Mineral Mining, Nonmetallic Mineral Mining (Except Stone and Coal), and Stone Mining. Data presented are for number of deaths and injuries by nature of injury (24), by disability of injury (3 classifications) and by cause.

Nuclear Power Plant Operating Experience - 1978, Annual Report, U.S. Nuclear Regulatory Commission, Dec. 1979, (Office of Management and Program Analysis). Data are presented on details of plant outages, by power plant, by cause.

Personal Communication: Alan Hoskin, Statistics Dept., National Safety Council; Norman Root, Supplemental Data System, Bureau of Labor Statistics, U.S. Department of Labor (also provided tables on causes of accidents at the workplace based on workman's compensation data); Pat Coleman, Division of Safety Research, National Institute of Occupational Safety and Health; Peter Reise, Health Interview Statistics Division, National Center for Health Statistics; Caryl Michelson, Office of the Analysis and Evaluation of Operational Data, Nuclear Regulatory Commission; Electric Power Research Institute; Columbus Southern Ohio Electric Company.

Home Related

Advance Data, National Center for Health Statistics, Vital and Health Statistics, March 7, 1978, (Peter W. Ries) pp. 12. Data presented are number of episodes of persons injured by selected characteristics (p. 8) by product type, (25 categories). Data are for 1975.

U.S. Consumer Product Safety Commission Annual Report Fiscal Year 1979, Part 2, U.S. Consumer Product Safety Commission, 1979. Data presented are estimated number of injuries requiring emergency room treatment associated with consumer products by 177 product groups.

Personal Communication: Joel Friedman, National Injury Information Clearinghouse, and Arthur MacDonald, Data Collection (NEISS) of the Consumer Product Safety Commission.

Public Related

Dams and Public Safety, U.S. Department of the Interior, Water and Power Resources Division (Old Bureau of Reclamation). Government Printing Office, 1980. Traces the history of dams and the kinds of problems associated with them which may lead to their failure. Special emphasis is placed on structures and experiences of the Bureau of Reclamation; however, the material presented is drawn from sources worldwide. The more significant accidents and failures are discussed in greater detail and provide further information on causes and consequences.

Lessons From Dam Incidents, USA, American Society of Civil Engineers, 1975, (Committee on Failures and Accidents to Large Dams of the U.S. Committee on Large Dams). Presents available data on dam incidents and analyzes the data from questionnaires with respect to the type of incident (i.e., severity), frequency and trend. The data collected (for the years 1966-1973) were combined with USA data collected for a previous report (Failures and Accidents to Large Dams, International Committee on Large Dams, 1966) to further reinforce any frequency or time trends. Writeups are also included for each dam that had one or more reported significant incidents using data from the questionnaire and from available references.

Personal Communication: Ted Glord, Army Corps of Engineers; Harry Hardin, Water Resources Support Center; Bruce Tschantz, Dam Safety Division, Federal Emergency Response Agency; American Society of Civil Engineers; American Association of State Highway and Transportation Officials.

Military

Material Failure Reports - 1977-1980. Military files were searched by the Army, Navy, and Air Force to retrieve records of accidents involving material failure. Results include narratives of all accidents and provide detailed information on number of deaths, injuries, property damage, and cause.

Storage-Related

Hazardous Material Incidents Reported to U.S. EPA Regional Offices from 1977-1979, U.S. EPA, Oil and Special Materials Control Division, Spill Prevention and Control. Report contains a synopsis of all incidents involving hazardous or toxic chemical spills.

Personal Communication: Harold Snyder, Oil and Special Materials Control Division, U.S. EPA; Kathy Gaul, Environmental Manager, Great Lakes Division, Waste Management Inc.

Recreation-Related

Personal Communication: U.S. Coast Guard, Office of Boating Safety.

Miscellaneous

Statistical Bulletin, Metropolitan Life Insurance Company, (various reports).

Statistical Abstract of the United States, 1979, U.S. Dept. of Commerce, Bureau of the Census.

Accident Facts, National Safety Council, 1979 (published yearly). Provides detailed analysis of accidents occurring at work, in the home, school and motor vehicles. Most of the data is on accidents in which deaths and injuries occurred, thus information on the extent of property damage is excluded. Aggregate cost estimates are provided, however, for property damage resulting from motor vehicle accidents and fire loss.

Environmental

Maler, Karl Goran and Ronald E. Wyzga, Economic Measurement of Environmental Damage. Organization for Economic Cooperation and Development, 1976. Reviews and suggests methods which can be used to estimate environmental damage functions and provides guidelines to ensure the resulting estimates are in accord with economic principles. An environmental damage function is an estimate of the relationship between given levels of environmental quality and monetary estimates of the environmental damage associated with these quality levels.

Mark, Jonathan, H., "A Preference Approach to Measuring the Impact of Environmental Externalities", Land Economics, Vol. 56, No. 1, February, 1980, (pp. 103-116). Outlines a theoretical model which suggests a relationship between externalities and property values.

National Environmental Statistical Report, prepared for Council on Environmental Quality and Resource and Land Investigations Program, U.S. Dept. of the Interior, October, 1975. MTR-6957, (Mitre Corporation). Report contains a variety of environmental and related data in approximately 200 statistical and summary tables. The tables are arranged by data type, under 16 sections: air quality, water quality, land use, solid waste, pesticides and toxic substances, agriculture and food supply, forests and wildlife, water resources, recreation, minerals, energy, transportation, housing, population, economics and environmental impact statements.

Sixth Annual Report of the Council on Environmental Quality, U.S. Government Printing Office, Washington, D.C., 1975, (Council on Environmental Quality), pp. 494-570.

Insurance Information - Property Damage

Insurance Fact, 1977, 1978, 1979 (published yearly). (Insurance Information Institute, New York. Contains selected data of general interest relating to property losses resulting from fire and boating accidents. Information also available on countrywide average paid claim costs for property damage resulting from auto accidents in private passenger cars. Other estimates provided for economic losses do not separate costs of bodily injury and property damage.

Product Liability Closed Claim Survey: A Technical Analysis of Survey Results, (Insurance Services Office) NYC, 1977. Contains numerous compilations of survey data on product and liability claims. Compilation has been produced from the closed claim data on 24,452 survey forms submitted by 23 participating companies. Data includes a breakdown of payment data by type of damage alleged; distribution of property damage economic loss by payment size and total economic loss; and cause of loss distribution of size of loss on both a claim basis and an incident basis.

Automobile Insurance Losses-Collision Coverage. Variations by Make and Series 1977, 1978 and 1979 Models, Washington, D.C., Dec. 1979. HCDI R72-2, (Highway Loss Data Institute). Describes variation in both frequencies and sizes of collision coverage claims for damage to 1977, 1978 and 1979 model year passenger cars.

APPENDIX F. INJURY COST MODEL SUMMARY*

The Injury Cost Model was originally developed by Technology + Economics, Inc. (T+E), for the Consumer Product Safety Commission. The objective of the model was to provide policymakers the ability to measure, on a monetary basis, the magnitude of the impact on society of a wide range of injuries associated with consumer products. The original research was conducted by T+E in 1975 and 1976 with subsequent revisions and modifications undertaken through the period to 1980.

The model is designed to interface directly with CPSC's National Electronic Injury Surveillance System (NEISS). NEISS is a statistically valid national sample of product-related injuries collected from 74 hospital emergency rooms throughout the country. NEISS permits estimation of injury frequencies on the basis of type of injury and body part injured, the age and sex of the victim, and the consumer product associated with the injury. The underlying objective of the Injury Cost Model is the development of disaggregated estimates of injury costs which can then be integrated with the NEISS data base to produce national estimates of injury costs according to the various dimensions of the NEISS sample. However, the model can be applied to any injury frequency data base whose dimensions are reasonably comparable with the NEISS data.

Several methodological factors strongly influenced the development of the Injury Cost Model. These included the importance of the concept of social cost in deriving estimates of injury costs, the need for a disaggregated or modular approach to the estimation of the separate components of injury costs, and, as noted above, the necessity of formulating the functional relationships in terms of the NEISS-contained variables.

The specification, estimation, and implementation of the model consisted of three discrete steps. First, at a conceptual level, the elements comprising injury costs were identified and a methodology for estimating these elements specified. Ultimately, twelve separate injury cost components were identified, with their sum constituting total injury costs. The second step involved the collection of the requisite data necessary to estimate each component. The major data sources included a large sample of medical insurance claims obtained from the Department of Defense, Civilian Health and Medical Program for the Uniformed Services (CHAMPUS), information regarding injury-associated work loss and restricted activity days from the National Health Interview Survey (NHIS), and a sample of court awards for pain and suffering. Estimation techniques included regression analysis, direct analytic solutions, and utilization of sample means from the disaggregation of large data bases. The final step in the model development involved the embodiment of the resultant injury cost algorithms in a set of computer programs compatible with the NEISS data. In addition, it was necessary to

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* This Appendix was prepared by Technology + Economics, Inc., of Cambridge, Massachusetts, under a subcontract from Battelle.

structure the programs so as to permit ready access to the model in a manner suitable for CPSC applications.

Given this general introduction to the nature, structure, and chronology of the Injury Cost Model, we now turn to a discussion of the estimation of the individual injury cost elements. As noted, the model is composed of twelve separate cost components. These include:

- Hospital costs
- Retreatment costs
- Foregone earnings
- Health insurance costs
- Product liability insurance costs
- Litigation costs
- Transportation costs
- Visitor foregone earnings
- Visitor transportation costs
- Pain and suffering costs
- Disability costs
- Valuation of loss of life.

Before proceeding, it should be noted that these cost categories represent three broad types of injury costs. First are those costs which represent direct expenditures associated with consumer product-related injuries. These reimbursable costs include hospital costs, insurance costs, litigation costs, and transportation costs. Second, foregone earnings represent the opportunity costs of time spent away from normal activities as a result of the injury. Finally, there are non-reimbursable costs whose value can be imputed only in terms of a marginal reduction in the risk of occurrence of that type of injury cost. Pain and suffering costs, disability costs, and valuation of loss of life comprise the third type of injury costs. We now turn to a consideration of each of the injury cost components.

Hospital Costs (and Retreatment Costs)

Hospital costs involve all medical and hospital expenditures for treatment of the victim of a consumer product-related accident. These expenditures include the costs of medical personnel, facilities, and other health resources required to treat the victim during the basic recovery period. Similar to hospital costs are retreatment expenditures associated with the long-run medical care of the victim. These retreatment costs, incurred after the basic recovery period, include expenditures for corrective surgery, treatment of chronic injuries, and so forth.

Estimates of medical costs on an injury-specific basis were derived from claim records of the CHAMPUS health insurance program of the Department of Defense. The CHAMPUS data contain information about the value of hospital and professional services for inpatient and outpatient claims for calendar years 1976, 1977, and 1978. The data set contains more than 600,000 claim records coded by age and sex of the claimant and by International Classification of Disease, Amended (ICDA) injury classification. These data were grouped into cells to obtain estimates of average medical costs for each injury classification and every age and sex group.

One major obstacle to utilizing the input variables derived from CHAMPUS data is that injuries are coded in terms of the ICDA classification system. In order to relate these variables to the NEISS injury data, which are coded according to a classification scheme specific to NEISS, the development of a mapping or correspondence between the ICDA and NEISS injury classifications was required. Because this correspondence is not, in general, one to one, a weighted averaging technique was also required in order to transform ICDA-coded variables into values classified according to the NEISS injury code.

Retreatment costs were based on an estimate of the probability that an injury of a given type results in additional treatment and on an estimate of the conditional probability that the retreatment will necessitate surgery. Expected or average retreatment costs for each injury type were then determined from estimates of representative retreatment costs for surgical and non-surgical cases.

Foregone Earnings

Foregone earnings reflect the social value of the time lost from an individual's normal activities as the result of an injury. The associated injury cost component consists of two multiplicative elements: (1) the number of bed days, restricted activity days, work loss days, and school loss days; and (2) the opportunity costs per day for each of these categories.

Data from the National Health Interview Survey permitted estimates of the time loss categories as a function of the age, sex, and employment status of the victim and the nature of the injury (ICDA-coded). Data were available for the years 1970-1978. However, due to the relatively small sample size, it was necessary to aggregate the NHIS data over a smaller number of injury groupings in order to derive reliable estimates for individual age, sex, and injury categories. In addition, the ICDA-NEISS injury code correspondence described above was required to relate the NHIS restricted activity estimates to the NEISS injury data base.

The opportunity costs of these activity restrictions were estimated in terms of the economic value of production losses due to the injury. These losses include the value of work performed in the labor market as well as the value of non-market activities performed at home and at school. The average opportunity cost per day for a given age-sex group depends on the labor force participation rate, the unemployment rate, and the school enrollment rate.

Health Insurance Costs

Since health insurance provides protection against medical costs incurred as the result of consumer product-related injuries, the costs of such insurance must necessarily be included in estimates of the societal costs of these types of injuries. The relevant magnitude to be evaluated involves the cost of providing the insurance and settling claims rather than the total amount of premiums paid. These costs include overhead costs such as statistical services, marketing, public relations, and so forth, as well as the adjustment costs of handling claims. On the basis of data from Blue Cross-Blue Shield and other insurance plans, a relationship was estimated which predicts health insurance costs for a given injury type in terms of a fixed component which reflects the average overhead costs of insurance provision and a variable component, proportional to the associated hospital and medical costs, which reflects the influence of the size of the claim on the resultant insurance cost.

Product Liability Insurance Costs

Product liability insurance provides protection to manufacturers and retail establishments against injury cost damages sought by victims of consumer product-related accidents. As in the case of health insurance, the relevant costs are those associated with providing the insurance and settling the claims rather than total premiums paid. On the basis of insurance data and prior studies in this area, estimates were obtained for: (1) the variable costs per claim which reflect the costs associated with settling the claim; and (2), average overhead costs per claim. Utilizing these estimates a relationship for estimating liability insurance costs per claim for a given injury was determined.

Litigation Costs

Litigation costs reflect the legal expenses incurred by injured parties where compensation is sought as the result of alleged negligence in consumer product-related accidents. Since not all product-related injuries result in litigation, estimates of expected litigation cost per injury depend on the probability that compensation is sought, the percentage of compensation attempts where legal counsel is retained, and the legal expenses in compensation attempts involving legal counsel. Legal expenses per litigation, in turn, depend on whether the case was settled out of court, the probability of a favorable verdict, and the size of the award. By combining estimates of the litigation probabilities obtained from studies of claim experience for product liability and automobile injuries with data on average product liability claim values, estimates of average litigation costs for a given injury type were developed which depend directly on the total cost of the injury.

Transportation Costs

The transportation cost component involves those expenditures associated with transporting persons in consumer product-related accidents to and from medical facilities. Transportation costs incurred during the recovery period as a result of bed visits by friends and relatives are treated separately as part of visitor costs.

The critical determinant of transportation costs is the mode of transportation, the principal options being automobile and ambulance. On the basis of assumptions regarding the probabilities of each transportation mode for both initial and return trips, given (1) the severity of the injury (the NEISS severity code) and the age of the victim, and (2) estimates of average costs per trip for each mode, estimates of average transportation costs per injury were developed as a function of the severity of the injury and the sex of the victim.

Visitor Costs

Visitor costs consists of: (1) transportation expenditures incurred by friends and relatives making visits during the victim's recovery period; and (2), the opportunity cost of the time spent transporting the victim to a medical facility or visiting the victim.

Visitor transportation costs were estimated in terms of a representative scenario regarding the number of visitors per victim bed day, the time spent with the victim, the miles traveled per visit, and the estimated cost per mile. Visitor opportunity costs depend on the number of visitors and the number of hours spent with the victim. The estimated total time is then valued in terms of the foregone earnings per hour.

Pain and Suffering Costs

Pain and suffering refers to the physical and emotional trauma and mental anguish associated with an injury. Pain and suffering costs are the assignment of an imputed monetized value for short-term and long-run effects endured by the injured party.

Imputing a cost to pain and suffering consisted of a two-step process involving: (1) the development of a physical measure of the level of pain and suffering; and (2), a translation of each identified level into a monetized value. Given the requirements that injury-specific aspects of costs be relatable to dimensions of the NEISS data base, the NEISS severity code was utilized as an index for physical pain. This code is an ordinal measure of severity based on the threat to life of specific types of injuries to different parts of the body.

The NEISS severity code was then related to monetary values of pain and suffering through a regression analysis of jury pain and suffering awards for personal injury and death in negligence cases. The result of this analysis was an empirical relationship between the NEISS severity code and the value of pain and suffering. This relationship was then utilized to assign pain and suffering costs on an injury-specific basis.

Disability Costs

Disability costs reflect the imputed value for functions foregone by the injured party permanently or for an extended period and the social loss associated with the victim's disability including the pain and suffering of friends and relatives and the replacement training costs borne by business.

The compensation for functions foregone by the injured party represents, in an approximate manner, the long-run analog of foregone earnings. The major difference concerns the fact that foregone earnings refer to losses in "productive" capacity, while disability encompasses degradation of all human functions, including both market and non-market activities. For the purposes of this study, disability costs for a given injury type and age-sex category were imputed on the basis of expected lifetime earnings and subjective estimates of the probability and extent of disability for each type of injury.

Valuation of Loss of Life

As in the case of pain and suffering and disability, the interpretation and treatment of valuation of loss of life must be fundamentally different from those cost components reflecting reimbursement for injury-related expenditures. Valuation of loss of life cannot be evaluated in terms of payment for a consumer product-related fatality. The relevant question, rather, is the value of a marginal reduction of the probability of dying in a consumer product-related accident. It is this imputed valuation of loss of life, as identified in the risk-reduction conceptual framework, which is the appropriate cost component to measure.

The valuation of loss of life includes the imputed value to both the individual (the potential fatality) and the rest of society (family, friends, and employer). It should be noted that the value of loss of life really measures not life-saving, per se, but increased life expectancy. In that sense, the imputed valuation of loss of life is sensitive to the age and sex of a consumer product-related fatality, since age and sex are primary determinants of life expectancy. For more details of this component, see Appendix G.

APPENDIX G. VALUATION OF LOSS OF LIFE*

Introduction

The valuation of loss of life is a particularly sensitive topic in cost/benefit calculations. For that reason, considerable discussion is devoted here to the definition and estimation of the value of loss of life.

No particular methodology for estimation of the value of loss of life or any specific estimates which purportedly represent the value of loss of life is endorsed. Rather, we have developed alternative values of loss of life, each derived from different methodologies, and suggested the merits of each approach.

Definition and Application

As in the case of pain and suffering and disability, the interpretation of valuation of loss of life must be fundamentally different from those cost components reflecting reimbursement for injury-related expenditures. Loss of life cannot be evaluated ex post in terms of monetary payment for a consumer product-related fatality. The relevant question, rather, is the value of a reduction of the probability of dying in an accident. In other words, for a small reduction of the risk of a premature death, there exists an imputed valuation of life which, when multiplied by this probability, yields the value of the risk reduction. This imputed valuation of life, as identified in the risk reduction conceptual framework, is the cost component we are attempting to measure.

Figure G-1 depicts graphically what we mean by valuation of loss of life. P, on the horizontal axis, represents the probability of an individual's surviving a specific time period (e.g., the next year) or a specific event or series of events (e.g., climbing the stairs). On the vertical axis, W represents an individual's lifetime wealth. Curve UU' is an indifference function indicating the individual's willingness to exchange wealth for an increase in survival probability (life expectancy). The value of loss of life is just the slope of the indifference function.

Note that Curve UU' in Figure G-1 is nonlinear (convex). As a result, the value of life, as measured by the slope of UU', is not unique but depends on the level of P. Higher risk activities imply larger concessions of wealth (and a larger value of life) for a marginal risk reduction. It is clear that the risk of fatality from fracture is quite small in absolute terms. What this means is that the relevant P is very close to 1 unity, approximately P* in Figure G-1.

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* This Appendix was prepared by Technology & Economics, Inc., of Cambridge, Massachusetts, under a subcontract from Battelle.

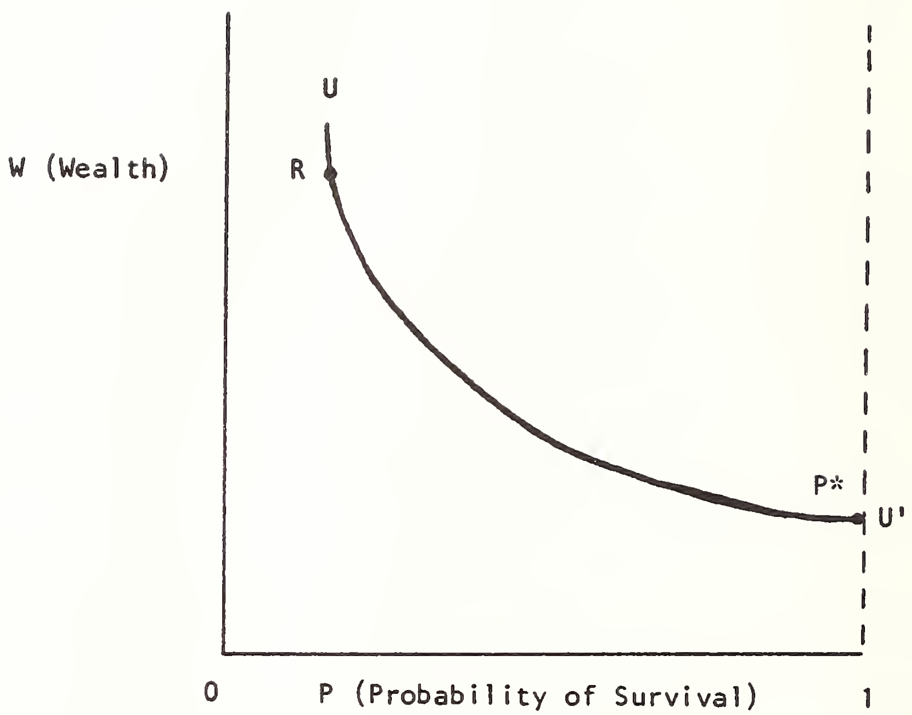

FIGURE G-1. THE VALUATION OF LOSS OF LIFE IN A RISK-REDUCTION FRAMEWORK

Having defined the meaning of valuation of loss of life, we turn now to its estimation. Three different approaches will be utilized: human capital, quality-adjusted life-years, and willingness to pay. A total of six (alternative) estimates of the value of loss of life will be derived.

The "Human Capital" Approach

The human capital approach to valuation of loss of life is based on an individual's economic worth as a productive member of society. In that sense, this approach is consistent with other human capital valuations, such as the returns to education.

The human capital approach to loss of life valuation is normally presented in one of two forms: the "net" value method or the "gross" value method. The "net" human capital method values the economic contribution lost by the remainder of society were an individual to die. The usual estimation procedure is to calculate the present discounted value of the individual's expected gross earnings minus consumption over the expected duration of his lifetime. This approach is unsatisfactory, however, because it ignores the interests of the potential victim. It disregards the interests of society ex ante and concentrates only on society ex post. Taken to its logical conclusion, this method suggests that the death of any individual whose expected discounted consumption exceeds his expected discounted earnings confers a net benefit on society. This category of individuals would include, at a minimum, most retired and disabled persons. The unpalatable implications of this approach stem directly from the assumptions concerning the value of production. The net contribution approach has merit only if we believe that resources derive value from investment alone.

The gross human capital method is probably the most widely used method of valuing lifesaving programs. In brief, this approach derives a value for loss of life by calculating the present discounted value of the individual's gross earnings over the anticipated remainder of his lifetime. Notice that expected gross earnings may be differentiated on the basis of the NEISS age and sex variables.

For the gross human capital approach, the estimation of the value of loss of life, for each age and sex category, is calculated using the following formula:

$$V_i = \sum_{t=\tau}^{\infty} Y_{it} P_{it}(\tau) \, (1 + r)^{-(t-\tau)}$$

where V_i is the value of life of an individual in the i^{th} age/sex category; Y_{it} is expected gross earnings, exclusive of returns on own-human capital assets, per individual in the i^{th} category; $P_{it}(\tau)$ is the probability in the current (τ^{th}) year of an individual in the i^{th} category being alive during the t^{th} year; and or C is the discount rate. The discount rate reflects a time preference for money, since money has an opportunity cost. As a result, income earned in the future is worth less than if it were currently available.

The values these variables assume were obtained from Cooper and Brody(6)*. Several values for the discount rate were offered. We assumed a "nominal" discount rate of twelve percent. However, we concurrently assumed that earnings in future years will, on average, increase by six percent because of inflation and by an additional two percent because of annual productivity increases. Thus, the "real" discount rate employed was (approximately) four percent. Finally, since Cooper and Brody's estimates were presented in 1972 dollars, we inflated their figures by 55.9 percent to convert their values to a 1978 base year. The present value estimates of expected future earnings, by age and sex, are provided in Table G-1. These estimates constitute the first option for the value of loss of life.

Quality-Adjusted Life-Years

The concept of quality-adjusted life-years (QALY) offers a solution to two recurring problems in the valuation of loss of life. The first problem is how to account for differences in the characteristics of the (expected) victims in placing a value on the loss of life. Often a single number is presented for the value of loss of life (e.g., $200,000 per life lost or saved), regardless of the characteristics of the victim. Using this approach, one need only to add up the number of lives saved and multiply by the value of loss of life in order to calculate the benefits of a fatality-reducing program. However, even though we conventionally use the terminology "lives saved", lives are not saved, but prolonged. The relevant question then becomes not how many lives are saved, but rather how many years has life been extended. Life expectancy, from this viewpoint, assumes crucial importance in placing value on human life.

The second problem concerns the fact that different years of an individual's life saved are not homogeneous; they vary in quality, however measured. QALY weights years of life saved according to an index of the quality of life during those years. Admittedly, any such index must be subjective in nature; nevertheless, if the basic relationships can be agreed upon, then the actual weights chosen should provide a reasonable approximation to the relative quality of years of life saved.

We assume that the principal determinant of the quality of a life-year is the age of the individual at the time the year is "consumed". The standard of quality is the "prime of life", the ages between 20 and 40. Slightly less desirable are the ages between 10 and 20 and between 40 and 60, followed by the ages from 0 to 10. The least desirable years are those after the age of 60. Poorer health and a reduction in available activities are the major reasons for scaling down later years. The ages from 0 to 20 are demoted in value because they are years of dependency. A quality-adjusted weighting of life-years, compatible with the criteria suggested above, is contained in Table G-2. In order that the average value per life-year be (approximately) unity, the weights for some years exceed unity.

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*References are found at the end of this Appendix.

TABLE G-1. VALUE OF LOSS OF LIFE: OPTION 1
PRESENT VALUE OF EXPECTED FUTURE EARNINGS

Age	Male	Female
Under 2	$156,737	$ 95,312
2- 4	163,863	99,516
5- 9	200,001	121,346
10-14	243,708	147,840
15-19	290,755	173,989
20-24	329,788	186,670
25-34	338,794	172,757
35-44	286,304	138,874
45-54	194,609	96,069
55-64	90,952	48,067
65+	12,499	7,980

Source: See Appendix VII, Section 3

TABLE G-2. WEIGHTS FOR LIFE-YEARS

Age	Weight (per year)
0- 9	.8
10-19	1.0
20-29	1.2
30-39	1.2
40-49	1.0
50-59	1.0
60-69	.8
70-79	.6
80-89	.4
90+	.2

Quality-adjusted life-years can be developed by combining life expectancy figures for individuals of a given age and sex with the weights presented in Table G-2. In order to be consistent with the human capital approach, life-years have been discounted by four percent per annum. The formula for calculating quality-adjusted life-years is:

$$QALY_i = \sum_{j=a_i}^{n_i} \left[\frac{1}{1.04}\right]^{j-a_i} q_j$$

where $QALY_i$ is the expected number of quality-adjusted life years of an individual in the i^{th} age and sex category; a_i is the age of potential death of the individual in the i^{th} category; n_i is the life expectancy (at age a_i) of an individual in the i^{th} category; and q_j is the weight representing the quality of life at age j. The number of quality-adjusted life-years associated with "saving" the life of an individual within a given NEISS age and sex category is given in Table G-3. Females at all ages have more QALY's than their male counterparts because they have a longer life expectancy.

What remains is to place a dollar value on each QALY. Because the concept of quality-adjusted life-years was developed primarily for cost-effectiveness purposes--that is, to evaluate the number of QALY's saved per dollar expended on alternative fatality-reducing policies--the literature on the subject provides little guidance on how to monetize the benefits per QALY. One plausible method, related to the human capital approach, is to evaluate QALY in terms of the present value of expected future earnings. In order to derive a value for QALY's, we have employed the ad hoc procedure of dividing the expected discounted future earnings of a male and female of every age, through life expectancy at birth (70 for males, 77 for females), and dividing by the expected number of QALY's for that age and sex. The magnitude of the quotient averaged over all ages, calculated separately for men and women, is the monetary value for QALY we shall use. In mathematical notation, the formula is:

$$\$/QALY = \sum_{i=0}^{ns} \left(\frac{VDFE}{QALY}\right)_{i,s} /ns$$

where the term in parenthesis is the value of discounted future earnings per quality-adjusted life-year of a potential victim of the i^{th} age (not age category) and the s^{th} sex, and ns is the life expectancy at birth of an individual of the s^{th} sex. The monetary value per QALY, as calculated from this equation, is $9,622 for males and $4,386 for females. Applying these figures to the QALY estimates in Table G-3 yields the value of loss of life estimates provided in Table G-4. These estimates, based on the integration of the human capital and quality-adjusted life-year approaches, constitute the second option for the value of loss of life.

TABLE G-3. EXPECTED NUMBER OF QUALITY-ADJUSTED LIFE-YEARS BY AGE AND SEX OF POTENTIAL VICTIM

Age	Male	Female
Under 2	37.60	38.68
2- 4	37.51	38.46
5- 9	37.02	38.27
10-14	35.85	36.98
15-19	34.22	35.88
20-24	32.15	33.66
25-34	27.41	29.20
35-44	21.00	22.82
45-54	15.26	17.30
55-64	9.57	11.19
65+	4.22	5.13

TABLE G-4. VALUE OF LOSS OF LIFE: OPTION 2 INTEGRATION OF QALY* AND DISCOUNTED FUTURE EARNINGS

Age	Male	Female
Under 2	$361,787	$169,650
2- 4	360,921	168,686
5- 9	356,206	167,852
10-14	344,949	162,194
15-19	329,265	157,370
20-24	309,347	147,633
25-34	263,739	128,071
35-44	202,062	100,089
45-54	146,832	75,878
55-64	92,083	49,079
65+	40,605	22,500

* Quality-adjusted life-years

Source: See Appendix Vii, Section 4

The "Willingness To Pay" Approach

In accordance with the interpretation prescribed earlier, probably the most appropriate measure of the value of loss of life would be one based on an individual's willingness to pay for a marginal increase in life expectancy. Certainly one's willingness to pay is the method used to value most other goods and services in the marketplace. As Schelling (9) points out, if individuals are willing to pay some amount to improve their probability of survival, then they should be allowed to pay that amount and reap the benefits.

The willingness to pay for a reduction in the risk of loss of life is usually calculated in one of two ways, either by consumer survey or by inference from consumers' observable market behavior. Estimating the value of lifesaving from consumer surveys suffers from the usual shortcomings of market surveys, namely, that hypothetical questions have proved to be a poor indicator of consumer behavior or choice. This is particularly true for questions about important events, since the mood and motive of actual choice are difficult to simulate. The poor performance of hypothetical questions in consumer surveys is compounded here by the fact that questions concerning death involve minute probabilities for awesome events. The average consumer is inexperienced in dealing with infinitesimal probabilities and with death in general; so any value ascribed to reducing the probability of death is probably not based on an analytic assessment and probably dominated by anxiety, which can be expected to accompany any contemplation about loss of life regardless of the level of risk or the amount of risk reduction.

Inferring the willingness to pay for fatality risk reduction from observable market behavior appears to be a more promising avenue. Two careful studies, by Blomquist(2) and by Thaler and Rosen(10), derive empirical estimates of the value of life based on market decisions involving risk of life. Properly employed, these two studies provide a reasonably reliable range of the willingness to pay for a reduction in risk to life.

Blomquist imputes a value of loss of life from data on seat-belt use, based on multivariate probit analysis for the typical driver (who chooses not to wear seat belts), the risk reduction from wearing a seat belt, and the costs of seat-belt use. When the benefits of risk reduction associated with non-fatal injuries are subtracted out, what remains is the trade-off between fatality risk reduction and the cost (disutility) of seat-belt use. For the average driver in the sample--aged 39 and .88 male--the empirical trade-off implies a value of loss of life of approximately \$368,000 in 1978 dollars.

Thaler and Rosen analyze a sample of adult male workers employed in different occupations in order to estimate risk-compensated wage differentials. Their regressions imply a valuation of loss of life for the average worker--a 42-year old male--of approximately \$200,000 in 1967 or \$410,000 in 1978 dollars. However, their estimate is subject to several modifications. First, the job risk premiums include the hazards of both injury and death. Calculations by Bailey(1) suggest a range for the percentage of the wage differential to be applied to injury reduction. The intermediate figure is 56 percent, leaving 44 percent for reduction in risk to life and implying a value of loss of life of \$180,400.

A second problem with the Thaler-Rosen results is that the market behavior toward risk is observable only on a biased sample. In general, workers in hazardous occupations are less averse to personal risk than are those who avoid such occupations. These workers are unrepresentative of the general population; hence, a valuation of loss of life based on an assessment of those who voluntarily assume risky activities would tend to underestimate the true value. Compensating for this sampling problem is a difficult task. A rough approximation of the bias can be derived by examining the difference in the valuation of loss of life in Blomquist's study between the average person who uses seat belts and the average person in the sample if he were to use seat belts. The relative difference, from 11.5 percent of the sample to the mid-point, corresponds to an increase in the valuation of loss of life of approximately 13.7 percent (assuming an elasticity of value of loss of life with respect to seat-belt use of .356, as derived from Blomquist's analysis). Assuming that worker risk assessment is distributed in a manner similar to consumer seat-belt risk assessment, then compensation for the biased risk aversion of the Thaler-Rosen sample requires increasing the value of loss of life by 13.7 percent, to $205,000.

Finally, the Thaler-Rosen results are biased because the actual wages for the workers in the sample are below the national average for all male workers of that age group. The average wage for a 42-year old male was approximately $9,050 in 1967 dollars, 37 percent higher than reported for the Thaler-Rosen sample. Adjusting the valuation of loss of life for this wage bias--how this adjustment was made will be discussed shortly--results in an increase of 17 percent over the previous estimates, to $240,000.

Recall that the Blomquist figure for the value of loss of life was calculated for the average driver in his sample--aged 39 and .88 male. By correcting for differences in life expectancy and the present value of discounted future earnings between men and women aged 39, the Blomquist value of loss of life should be increased to $380,000 for a 39-year old male. Again, the basis for this adjustment will be explained shortly.

In summary, the willingness to pay for a reduction in risk to life, based on the observable market behavior of the Thaler-Rosen and Blomquist samples, yields values of loss of life between approximately $240,000 and $380,000 for a 40-year old male. Although the estimates from these two studies are not close in magnitude, they do offer a broad range within which we might expect the "true" value to fall. Given the large number of assumptions required to derive the reported estimates, and the fact that worker and consumer samples may be intrinsically different, then the variation in the results should not be too surprising. In any case, if we give each study equal weight, the average value of loss of life for a 40-year old male would be approximately $310,000.

The question remains how to estimate the value of loss of life for individuals of different ages and sex. In order to resolve this problem, we shall resort to the tools developed in prior sections--discounted future earnings and QALY. Presumably, increased wealth implies a greater desire and ability to pay for risk reduction. This relationship is corroborated by Blomquist, who finds that the value of lifesaving increases as discounted future earnings increase, a 10 percent increase in the latter inducing a 3.1

percent increase in the former. Similarly, an increase in life expectancy, and therefore an increase in quality-adjusted life-years, should have a positive effect on the value of lifesaving. Although the precise impact of changes in foregone earnings and quality-adjusted life-years is difficult to predict, we shall assume that these two variables receive equal weight and that the combination of changes in these variables will have a proportional effect on the value of loss of life. The value of loss of life for an individual in any NEISS age/sex category can thus be derived by comparing his foregone earnings and quality-adjusted life-year estimates (from Tables G-1 and G-3) with the estimates for males in the 35 to 44 age category using the following formula:

$$W_i = W^* \quad \frac{V_i}{V^*} \cdot \frac{QALY_i}{QALY^*}$$

where W_i, V_i, and $QALY_i$ are the value of loss of life, discounted future earnings, and quality-adjusted life-years, respectively, for an individual in the i^{th} age/sex category, and the asterisk denotes corresponding values ($310,000, $286,304, and 21.00, respectively) for a male between the ages of 35 and 44. Of course, W^* is just the averaged willingness to pay value of lifesaving derived from the Blomquist and Thaler-Rosen studies. Earlier adjustments to the estimates reported in these studies, to account for age and sex differentials, were based on this formula.

The value of loss of life estimates generated by the preceding equation are displayed in Table G-5. These estimates, based on the willingness to pay approach and adjusted both for discounted future earnings and quality-adjusted life-years, constitute the third option for the value of loss of life.

In light of the large number of manipulations required to derive the estimates for the third option, is it likely that they bear any resemblance to the "true" value of loss of life? Economic theory and intuition would suggest that the answer is "yes". First, quality-adjusted life-years (or some other weighted measure of life expectancy) would seem to have a positive influence on the value of lifesaving. Even if an individual were no longer earning income, he would be willing to pay for a reduction in risk to life. (The ability to pay, in this case, would come from wealth saved in previous years.) The point is that periods of earning and periods of consumption (utility) do not necessarily coincide; indeed the motivation for production in earlier years is often the enjoyment of life without work (disinvestment) in later years. Quality-adjusted life-years permits the continuity of the stages of life to be maintained in valuing the loss associated with the premature termination of life.

A second point is that all of the values for loss of life in the third option exceed the corresponding present value of expected future earnings (compare Tables G-5 and G-2). Several sources argue that this relationship must obtain; that the value of loss of life must exceed foregone earnings. Conley[3,4], for example, shows that with a concave lifetime-consumption utility function and for a value of expected lifetime consumption above some low, presumably near-subsistence level, the value of human life

TABLE G-5. VALUE OF LOSS OF LIFE: OPTION 3 WILLINGNESS TO PAY ADJUSTED BY DISCOUNTED FUTURE EARNINGS AND QALY*

Age	Male	Female
Under 2	$306,900	$242,730
2- 4	313,410	247,690
5- 9	344,100	272,490
10-14	365,180	295,740
15-19	398,970	315,890
20-24	411,680	316,820
25-34	385,330	283,960
35-44	310,000	225,060
45-54	217,930	163,060
55-64	117,800	92,690
65+	29,140	25,730

* Quality-adjusted life-years

Source: See Appendix VII, Section 5

exceeds expected lifetime earnings. Cook and Graham(5) treat human life as one commodity within the general class of irreplaceable commodities, where an irreplaceable commodity can be identified according to whether, in its owners view, there are equivalent commodities available on the market. Adopting a state-preference approach, with the two states "alive" and "dead", the authors find that the value of loss of life is bracketed by what the owner would pay to avoid its loss and by the amount of money required to fully compensate him for its loss.* Furthermore, these brackets correspond, under certain assumptions, to the present value of expected future earnings as a lower bound and the infinite amount required as compensation for immediate, certain death as an upper bound. Conley's analysis follows from a maximization of the lifetime utility of wealth whereas Cook and Graham rely on the maximization of lifetime utility, with wealth as one of its arguments. The latter function would appear to be more flexible and realistic, allowing non-material activities to contribute to the value of human life and increasing its value relative to discounted future earnings. In summary, the consensus is that the human capital approach to valuing human life constitutes only a lower bound to the value we desire. The third option satisfies this condition.

Finally, some support for the values of loss of life represented by the third option can be obtained by examining the elasticity of the value of life with respect to foregone earnings. Conley indicates that in the usual case, above some critical level of lifetime consumption, this elasticity must be less than unity. Blomquist develops an empirical estimate of .31 as the elasticity evaluated for the average driver. In the third option, the elasticity of the value of life with respect to foregone earnings, E_{wv}, can be represented by the following equation:

$$E_{wv} = \frac{1}{2}\sqrt{\frac{V_i}{V^*} \cdot \frac{QALY_i}{QALY^*}}$$

Based on the figures in Tables G-1 and G-3, the average value of E_{wv} is roughly .45, which falls within the boundaries established by Conley's and Blomquist's studies.

Adjustments To Reflect the Societal Value of Loss of Life

The discussion to this point has been predicated on the assumption that either the social value of loss of life is restricted to the victim's loss or the victim's value of loss of life incorporates the loss to family and the rest of society. The former assumption corresponds to the potential victim as a "lone bachelor", without family or friends who would value a reduction in his risk to life. The latter assumption, probably more realistic, is that the family is the appropriate decision unit in valuing lifesaving activity (so that the value of loss of life for any family member in the previous options is the composite value to the family) and that any other social loss is negligible.

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*One cannot, of course, be directly compensated for his own death.

Several studies suggest, however, that the societal value of loss of life is well in excess of those developed for the previous options. Fromm(7), in a 1960 study of civil aviation, estimated that the total social value of loss of life, ignoring losses specific to the airline industry, was 75 percent more than the present value of expected future earnings. Joksch(8), in a 1975 study of highway traffic safety, derived estimates, when adjusted for a 4 percent discount rate, that were approximately 60 percent higher. The societal losses in these studies, in addition to the victim's own loss of life, included the loss to family, friends, community, employer, and government. There is no question that if these social losses exist they should be included in the valuation of loss of life. Just as it was improper to exclude the value of lifesaving to the victim in the human capital approach (i.e., the "net" human capital approach), it is equally improper to exclude the value to society.

Probably the best way to derive estimates of the magnitude of social loss is to attempt to place a value on each of its components. Bailey provides some evidence that the government component of the social loss is equal to the amount of indirect business taxes on the victim's foregone labor income. That value translates into approximately 9 percent of the individual's value of loss of life. Fromm estimates that employer losses, presumably from the foregone benefits of job-specific training (not captured in the employee's wage), constitute approximately 2 percent of the individual's value of loss of life. Fromm further suggests that the loss to community and friends is equal to about 13 percent of the individual's value of loss of life. Bailey corroborates the magnitude of this estimate by considering the willingness of society to subsidize the insurance premiums for workers in higher risk positions. Based on the benefits versus the costs of survivor's benefits from social security, he imputes a "third-party" contribution of approximately 15 percent of the individual's value of loss of life. Using an averaged figure of 14 percent for the loss to community and friends, the total social loss, net of family loss, is approximately 25 percent of the value of loss of life calculated in the three earlier options.

The remaining issue is how to value the family loss associated with a fatality. Here, there appears to be virtually no basis for selecting a value. Fromm suggests that the family loss is equal to almost 60 percent of the individual's discounted future earnings. If we accept this crude number, and further assume that approximately half this amount is already captured in the individual's life valuation, then the individual's value of loss of life would have to be increased by 30 percent to encompass the loss to family members.

Based on the previous discussion, the total societal losses--for the loss to family, friends and community, employer, and government--would correspond to roughly 55 percent of the individual's value of loss of life. Admittedly these estimates are highly subjective, but that should not constitute a justification for ignoring societal losses to the extent they are not reflected in the individual's value of loss of life. In order to include the societal loss in loss of life valuation, the estimates presented in the earlier options must be increased by 55 percent. Tables G-6, G-7, and G-8 contain revised estimates of the value of loss of life for Option 1, Option 2, and Option 3, respectively. These revised estimates, which are adjusted to

TABLE G-6. VALUE OF LOSS OF LIFE: OPTION 1a PRESENT VALUE OF EXPECTED FUTURE EARNINGS PLUS ADDITIONAL SOCIETAL LOSS

Age	Male	Female
Under 2	$242,942	$147,734
2- 4	253,988	154,250
5- 9	310,002	188,086
10-14	377,747	229,152
15-19	450,670	269,683
20-24	511,171	289,339
25-34	525,131	267,773
35-44	443,771	215,255
45-54	301,644	148,907
55-64	140,976	74,504
65+	19,373	12,369

Source: See Appendix VII, Section 6

TABLE G-7. VALUE OF LOSS OF LIFE: OPTION 2a INTEGRATION OF QALY AND DISCOUNTED FUTURE EARNINGS PLUS ADDITIONAL SOCIETAL LOSS

Age	Male	Female
Under 2	$560,770	$262,958
2- 4	559,428	261,463
5- 9	552,119	260,171
10-14	534,671	251,401
15-19	510,361	243,924
20-24	479,488	228,831
25-34	408,795	198,510
35-44	313,196	155,138
45-54	227,590	117,611
55-64	142,729	76,072
65+	62,938	34,875

* Quality-adjusted life-years

Source: See Appendix VII, Section 6

TABLE G-8. VALUE OF LOSS OF LIFE: OPTION 3a WILLINGNESS TO PAY ADJUSTED BY DISCOUNTED FUTURE EARNINGS AND QALY* PLUS ADDITIONAL SOCIETAL LOSS

Age	Male	Female
Under 2	$475,695	$376,232
2- 4	485,786	383,920
5- 9	533,355	422,360
10-14	566,029	458,397
15-19	618,404	489,630
20-24	638,104	491,071
25-34	597,261	440,138
35-44	480,500	348,843
45-54	337,792	252,743
55-64	182,590	143,670
65+	45,167	39,882

* Quality-adjusted life-years

Source: See Appendix VII, Section 6

include the societal value of lifesaving, represent the final three options for the value of loss of life.

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APPENDIX H. DETAILED COMPUTER PRINTOUTS OF SELECTED INPUT/OUTPUT MATRICES (SEPARATELY BOUND)

Direct Technical Coefficients, World I

Direct Technical Coefficients, World II

Direct Technical Coefficients, World III

Capital/Output Coefficients, World I

Capital/Output Coefficients, World II

Capital/Output Coefficients, World III

Useful Lives, World I

Growth Matrix

Social Capital Infrastructure, World I

Average Annual Capital Replacement Rate, World I

Average Annual Capital Replacement Rate, World II

Average Annual Capital Replacement Rate, World III

Direct and Indirect Effects, World I

Direct and Indirect Effects, World II

Direct and Indirect Effects, World III

Dollar Value of Interindustry and Final Transactions, World I

Dollar Value of Interindustry and Final Transactions, World II

Dollar Value of Interindustry and Final Transactions, World III

Dollar Value of Interindustry and Final Transactions, World I minus World II Difference

Dollar Value of Interindustry and Final Transactions, World I minus World III Difference

Dollar Value of Interindustry and Final Transactions, World III minus World II Difference

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