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ECONOMIC ASPECTS OF FIRE SAFETY IN HEALTH CARE FACILITIES: GUIDELINES FOR COST-EFFECTIVE RETROFITS

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards

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Robert E. Chapman and Phillip T. Chen

Center for Building Technology

and

William G. Hall

Center for Applied Mathematics
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

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Luther H. Hodges, Jr., ***Under Secretary***

Jordan J. Baruch, ***Assistant Secretary for Science and Technology***

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PREFACE

This research was conducted under the sponsorship of the Center for Fire Research and the Department of Health, Education and Welfare by the Applied Economics Group, the Center for Building Technology, and the Operations Research Division, Center for Applied Mathematics, National Engineering Laboratory, National Bureau of Standards.

This report is a product of the Fire and Life Safety Program. This program is a joint Department of Health, Education and Welfare (HEW) and National Bureau of Standards (NBS) effort directed at the development of rational, technically sound solutions to fire safety problems in health care facilities. In addition to the types of work described in this report, the joint HEW/NBS program has produced products in the areas of decision analysis, fire and smoke detection, smoke movement and control, automatic extinguishment, and behavior of institutional and other populations in fire situations.

This study develops a computerized procedure which helps identify the least-cost means of retrofitting a fire zone in a health care facility to achieve compliance to the Life Safety Code. The procedure also identifies from 10 to 20 retrofit alternatives, some of which are quite close in cost to the least-cost solution. The procedure is intended to be used as a management tool to facilitate the design selection process by providing both information on relative costs and a chance to match common retrofit packages across fire zones.

Special appreciation is extended to Ms. Brenda Edison who provided invaluable editorial services. Appreciation is extended to Drs. Harold E. Marshall and John S. McConnaughey, Applied Economics Group, who reviewed the economic aspects of this paper. Appreciation is also extended to Ms. Patsy Saunders, Operations Research Division, and Mssrs. James Pielert, Rehabilitation Technology Program, Harold E. Nelson and A. J. Shibe, Center for Fire Research, who provided many useful suggestions for improving the treatment of certain topics in this paper. Special appreciation is extended to Dr. Alan J. Goldman, Operations Research Division, whose stimulating discussions provided guidance and encouragement throughout this effort.

ABSTRACT

This study focuses upon one aspect of the fire safety problem in health care facilities; the use of the Fire Safety Evaluation System developed by the Center for Fire Research at the National Bureau of Standards for determining equivalence to the Life Safety Code. The Life Safety Code, a voluntary code developed by the National Fire Protection Association, is currently the most widely used guide for identifying the minimum level of fire safety in buildings. Using the Fire Safety Evaluation System as a basis, this study develops a computerized procedure which permits the least-cost means of achieving compliance to the Life Safety Code in health care facilities to be identified. Since each of the parameters used in the Fire Safety Evaluation System has a unique value which corresponds to strict compliance, it is possible to quantify the cost savings attributable to the use of the Fire Safety Evaluation System over strict compliance to the Life Safety Code. Preliminary studies conducted by the National Bureau of Standards of a prototypical hospital have concluded that the use of this computerized procedure can result in cost savings of 50 percent or more over those associated with strict compliance to the Life Safety Code.

Keywords: Applied economics; building codes; building economics; economic analysis; fire safety; health care facilities; hospitals; life safety; mathematical programming; nursing homes; renovation.

EXECUTIVE SUMMARY

The identification of cost-effective levels of fire safety in health care facilities is a major concern to hospital administrators, fire safety engineers and public policy makers. Rising construction and operating costs coupled with more stringent building codes and continuing advances in medical and building technology have complicated the issue, forcing health care facility administrators to assess carefully the alternative means through which they can design, construct or update their facilities.

This study focuses on one aspect of the fire safety problem in health care facilities; the use of the Fire Safety Evaluation System developed by the Center for Fire Research at the National Bureau of Standards for determining equivalence to the Life Safety Code. The Life Safety Code, a voluntary code developed by the National Fire Protection Association, is currently the most widely used guide for identifying the minimum level of fire safety in buildings. Although the Life Safety Code may be thought of as prescriptive since it prescribes fixed solutions for life safety in designated occupancies, the performance concept can be explicitly introduced through a provision which allows for equivalent solutions. In light of this provision the National Bureau of Standard's Center for Fire Research, through support from the Department of Health, Education and Welfare, has developed a system for determining how combinations of several widely accepted fire safety systems can be used to provide a level of safety equivalent to that required in the 1973 Life Safety Code.

Using the Fire Safety Evaluation System as a measurement tool, this study develops a computerized procedure which helps identify the least-cost means of achieving compliance to the Life Safety Code. Since each of the parameters used in the Fire Safety Evaluation System has a unique value which corresponds to strict compliance, it is possible to quantify the cost savings attributable to the use of the Fire Safety Evaluation System over that of strict compliance. Preliminary studies conducted by the National Bureau of Standards have concluded that the use of a computerized version of the Fire Safety Evaluation System can result in savings of 50 percent or more over the cost associated with strict compliance to the Life Safety Code.

In addition to identifying the least-cost solution, the procedure also identifies from 10 to 20 retrofit alternatives, some of which are quite close in cost to the least-cost solution. These retrofit alternatives are made available to facilitate the design selection process by providing information on relative costs and the opportunity to match common retrofit packages across fire zones. The use of such alternatives may result in a considerable saving of time in defining a comprehensive retrofit strategy for the entire building. The provision of retrofit alternatives should also simplify the problem of assessing the impacts of non-construction costs on the retrofit decision. The computerized procedure also contains a series of user options which make it possible to alter the cost of any retrofit, preclude a retrofit, force a retrofit to be included, or demand a higher level of safety than required by the Life Safety Code.

A prototypical hospital design is developed in order to illustrate how the computerized procedure would be used to solve actual fire safety problems. The prototypical hospital is patterned after a 300 bed general hospital built around 1960. It is constructed with structural steel framing protected by a fire resistive concrete covering, reinforced concrete floors, fixed windows, and masonry exterior walls.

Application of the Fire Safety Evaluation System to the prototypical hospital indicates that all fire zones in areas of patient use, with the exception of the fire zone containing the emergency room, require some type of retrofitting. Information on the scope and complexity of the retrofit alternatives is obtained from a series of floorplans for the prototypical hospital. This information is used as input for the computerized procedure.

Results from the case study indicate that the prototypical hospital could be upgraded to achieve compliance to the Life Safety Code for approximately $115,000 if the Fire Safety Evaluation System is used. The cost of achieving compliance through adherence to the prescriptive provisions of the Life Safety Code would cost approximately $250,000. Although a significant portion of the cost of strict compliance to the Life Safety Code was due to the installation of an exit stairwell (to remove a dead-end corridor), it is shown that the use of the Fire Safety Evaluation System could achieve compliance with the exit stairwell included in the retrofit package for approximately $185,000. Furthermore, the entire facility could be totally sprinklered for approximately $160,000 if the Fire Safety Evaluation System is used. Thus, even though high-cost items are included, significant savings result due to the inherent flexibility that the use of the Fire Safety Evaluation Systems offers to decision makers.

It is important to note that the procedure developed in this report has three limitations which are now being studied. These limitations relate to (1) the input requirements for the computerized procedure, (2) the cost estimating relationships used with the procedure, and (3) the need to use the NBS computer facility and staff to execute the computerized procedure. All of these limitations may be resolved through research and development activities proposed in this report. The major concern, and the reason for continued research in this area, is that both the input requirements and the cost estimating relationships are facility dependent. (Modifying the procedure for execution on other computer systems without the assistance of NBS staff is a rather straight-forward process.) More specifically, both the input requirements and the cost estimating relationships have been tailored to the typical hospital design analyzed in the case study. Additional research may conclude that certain health care facility types will require slightly different inputs. Perhaps more serious is that the cost estimating relationships currently being used in the computerized procedure are location and time dependent as well as being facility dependent. The development of cost estimating relationships which permit local market conditions and the condition of the health care facility to register their effects on the anticipated retrofit costs is a major goal of the current and planned research efforts. Ideally these relationships could be tied to a nationally recognized building cost index which would allow labor and material prices to be unambiguously altered to control for cost growth and regional price differences.

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SI CONVERSION UNITS

The conversion factors and units contained in this report are in accordance with the International System of Units (abbreviated SI for Systeme International d'Unites). The SI was defined and given official status by the 11th General Conference on Weights and Measures which met in Paris, France in October 1960. For assistance in converting U.S. customary units to SI units, see ASTM E 380, ASTM Standard Metric Practice Guide, available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103. The conversion factors for the units found in this Standard are as follows:

Length

1 in = 0.0254* meter

1 ft = 0.3048* meter

1 mil = 0.001* in

1 yd = 0.9144* meter

Area

1 in^2 = 6.4516* x 10^{-4} $meter^2$

1 ft^2 = 0.0929 $meter^2$

1 yd^2 = 0.836 $meter^2$

Volume

1 in^3 = 1.639 x 10^{-5} $meter^3$

1 liter = 1.00* x 10^{-3} $meter^3$

1 gallon = 3.785 liters

Temperature

°C = 5/9 (Temperature °F -32)

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*Exactly

Containing the costs of health care services is a major goal of health care facility administrators. Innovation in the construction and remodeling of their facilities is an important step.

1. INTRODUCTION

1.1 BACKGROUND

The identification of cost-effective levels of fire safety in health care facilities is a major concern to hospital administrators, fire safety engineers and public policy makers. Rising construction and operating costs coupled with more stringent building codes and continuing advances in medical and building technology have complicated the issue, forcing health care facility administrators to assess carefully the alternative means through which they can design, construct or update their facilities. Although multiple death fires in health care facilities are rare occurrences, the potential for major losses of life and property does exist and should be recognized in the selection of fire safety measures.

This potential and its implied need for a national commitment to fire safety in health care facilities has been emphasized in numerous congressional hearings.[1]

The National Fire Protection Association (NFPA) has long been recognized as a vehicle through which such a national commitment could be achieved. For over 60 years the NFPA has been a leader in the development of voluntary codes which establish acceptable fire safety levels. The Life Safety Code (NFPA 101-1973) is currently the most widely used guide for identifying the minimum level of fire safety in buildings. Although the code may be thought of as prescriptive, since it prescribes fixed solutions for life safety in designated occupancies, the performance concept can be explicitly introduced through a provision which allows for equivalent solutions. In particular, Provision 1-3118 states:

> Nothing in this code is intended to prevent the use of new methods or new devices, providing sufficient technical data is submitted to the authority having jurisdiction to demonstrate that the new method or device is equivalent in quality, strength, fire resistance, effectiveness, durability, and safety to that prescribed by this code.[2]

In light of this provision, the National Bureau of Standards' Center for Fire Research through support from the Department of Health, Education and Welfare has developed a system for determining how combinations of several widely accepted fire safety systems could be used to provide a level of safety equivalent to that required in the 1973 Life Safety Code.[3] The equivalency methodology which emerged from this effort is particularly attractive since it lends itself to computer optimization techniques. Such an optimization technique should result in improved fire safety in health care facilities because of its potential for resolving many of the differences of opinion surrounding the cost impacts of fire safety in health care facilities in general and the Life Safety Code in particular. To see better why this is so, a brief examination of the pros and cons of improved fire safety in health care facilities is useful.

Proponents of increased levels of fire safety cite incidents such as those which occurred in Chicago where 32 persons died and 50 were injured in two nursing homes. Investigations of these and other nursing

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1 Tragedy of Multiple Death Nursing Home Fires: The Need for a National Commitment to Safety, Select Committee on Aging, Subcommittee on Long-Term Care, September 1976.

2 Code for Safety to Life from Fire in Buildings and Structures, National Fire Protection Association, NFPA 101-1973, p. 101-2.

3 H. E. Nelson and A. J. Shibe, A System for Fire Safety Evaluation of Health Care Facilities, National Bureau of Standards, NBSIR 78-1555, November 1978.

home fires resulted in the conclusion that the installation of sprinkler systems probably would have averted the tragedies.[1] The cost of such systems was expected to be between $393 and $625 per bed.[2]

Opponents argue that hospitals and nursing homes are already affected by more regulations than any other building type. Modifications required to meet the higher levels of safety identified in the Life Safety Code will undoubtedly entail substantial outlays. In addition to these capital expenditures, federal regulations stipulate that certification of a health care facility for participation in Medicare and Medicaide is dependent upon the facility's compliance with the Life Safety Code. Published estimates for each potential year of human life saved through strict compliance to the Life Safety Code range as high as $12.7 to $63.5 million for hospitals and $1.1 to $1.6 million for nursing homes.[3]

1.2 PURPOSE

The purpose of this report is to describe the economic, mathematical, and engineering considerations that went into the development of a computerized procedure which permits the least-cost means of achieving compliance to the Life Safety Code to be identified.

The computer program discussed in this report is particularly useful because it is based on the equivalency methodology developed by the Center for Fire Research. Since the NFPA is in the process of adopting this equivalency methodology into the Life Safety Code, any solutions from the computer program will satisfy Provision 1-3118 of NFPA 101-1973. Furthermore, since each of the parameters used in the equivalency methodology has a unique value which corresponds to strict compliance, it is possible to quantify the cost savings attributable to a performance based approach or equivalency methodology over that of strict compliance. Although the procedure is useful for both new and existing facilities, it is anticipated that its primary use will be in identifying alternative courses of action open to administrators faced with retrofitting existing facilities.

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1 Federal Fire Safety Requirements Do Not Insure Life Safety in Nursing Home Fires: Report to Congress, Comptroller General of the United States, Washington, D.C., June 1976.

2 Ibid.

3 R. Freeley, D. C. Walsh, and J. E. Fielding, "Structural Codes and Patient Safety; Does Strict Compliance Make Sense?" American Journal of Law and Medicine, Volume 3, Number 4, Winter 1977-78, pp. 447-454.

The computer program uses as its primary input information collected during the course of any thorough fire safety evaluation. This information permits the current state of the health care facility to be unambiguously identified. The least-cost or optimal combination of retrofits is based on:

(1) the current state of the health care facility;
(2) the minimum passing "score" needed to achieve compliance; and
(3) the anticipated costs of each retrofit measure.

The computer program then analyzes other retrofit combinations to see if alternatives might exist which are close to the one identified as optimal. The optimal combination of retrofits and any alternatives which the program produces (usually between 10 and 20) are then summarized in tabular form so that they may be ranked from least costly to most costly. This approach provides health care facility decision makers with greater flexibility in choosing among retrofit combinations. In particular, through the consideration of alternatives, the decision maker is able to assess more effectively the impact that nonconstruction costs would have on the choice of the optimal retrofit combination.

1.3 SCOPE AND APPROACH

The general plan of this report is to describe briefly the Life Safety Code and the equivalency methodology; to discuss the computer program based on the equivalency methodology; and to identify and discuss the relevant engineering considerations which must be exercised in order to use this approach in solving a particular problem. Specifically, this report is organized as follows:

Chapter 2 describes the Life Safety Code and its effect upon health care facilities. The concept of a fire zone in a health care facility is then developed. The equivalency methodology is derived from the Life Safety Code by focusing on a small set of safety parameters in a single fire zone. A means for identifying the current state of a fire zone in a health care facility is then presented. An analysis of the costs of strict compliance versus the performance based equivalency methodology is provided to stress the inherent advantages of the computerized approach. A brief description of the computer program and its method of solution is then presented.

Chapter 3 is intended to establish a framework that will enable health care facility administrators to use this approach in solving their own fire safety problems. Crucial factors which affect costs and which were used in the selection of prototypical building designs are first discussed. A prototypical hospital design is then presented. Using the results of a series of hypothetical safety evaluations, the computer program is exercised to solve for the least-cost means of achieving compliance to the

Life Safety Code. This cost, as well as the costs of the alternative solutions, are then compared to the costs of strict compliance in order to demonstrate the flexibility available to the decision makers who use the equivalency methodology.

It is important to note that the procedure developed in this report has three limitations which are now being studied. These limitations relate to (1) the input requirements for the computerized procedure, (2) the cost estimating relationships used with the procedure, and (3) the need to use the NBS computer facility and staff to execute the computerized procedure. All of these limitations may be resolved through research and development activities proposed in this report. The major concern, and the reason for continued research in this area, is that both the input requirements and the cost estimating relationships are facility dependent. (Modifying the procedure for execution on other computer systems without the assistance of NBS staff is a rather straight-forward process.) More specifically, both the input requirements and the cost estimating relationships have been tailored to the typical hospital design analyzed in the case study. Additional research may conclude that certain health care facility types will require slightly different inputs. Perhaps more serious is that the cost estimating relationships currently being used in the computerized procedure are location and time dependent as well as being facility dependent. The development of cost estimating relationships which permit local market conditions and the condition of the health care facility to register their effects on the anticipated retrofit costs is a major goal of the current and planned research efforts. Ideally these relationship could be tied to a nationally recognized building cost index which would allow labor and material prices to be unambiguously altered to control for cost growth and regional price differences.

Computer systems are an integral part of many health care faciities. Consequently, experience gained in these areas could enhance the ease with which the Fire Safety Evaluation System could be applied.

2. FIRE ZONE SAFETY IN HEALTH CARE FACILITIES

2.1 THE LIFE SAFETY CODE

In recent years, the concept of fire safety has changed dramatically. This is due not only to more advanced and complicated technology, but also to changes in social structure. In the last 150 years fire safety has taken on meaning beyond merely preventing major conflagrations through the use of public fire departments. Today the emphasis is on prevention through the development of product standards which significantly reduce the probability of ignition for objects such as upholstered furniture within the building.[1] Although the efficiency of public fire departments and the consideration of product standards are both of fundamental importance in any systematic treatment of the fire safety problem, careful consideration must also be given to the goal of limiting fires to the building of origin. Historically, this goal has been addressed through the use of building codes. This report focuses on that aspect of the fire safety problem. Particularly, all analyses of the fire safety problem are dealt with exclusively in terms of the Life Safety Code,[2] since it is currently the most widely used means for identifying "acceptable" levels of fire safety.[3]

Since its origin in 1913, the Life Safety Code has been constantly revised as more reliable technical and empirical evidence has become available. The National Fire Protection Association's early work on the Life Safety Code was concerned primarily with the identification and analysis of the causes of death in major fires. From these analyses came recommendations for fire drills, standards for construction of stairways and fire escapes, as well as guidelines on the placement of the means of egress. National attention was drawn to the importance of adequate exits and related fire safety features in the tragic fire at the Coconut Grove Night Club in Boston in 1942 where 492 persons were killed. Other major fires in subsequent years further underscored the requirement that careful attention be given to the question of adequate means of egress.

Spectacular fires, such as the one at the Coconut Grove Night Club, resulting in major losses of life and property and large numbers of injuries, led to the increased use of the NFPA document for legal regulatory purposes. Unfortunately, the numerous advisory provisions contained in the document necessitated that a major revamping of the

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[1] J. W. Lyons, "Fire Research and Fire Safety: A Status Report on the Situation in the United States," Fire Standards and Safety, American Society of Testing and Materials, Special Technical Publication 614, A. F. Robertson, ed., 1977.

[2] The Life Safety Code was developed by the National Fire Protection Association. It is important to point out that the Life Safety Code is a voluntary code. Although the Life Safety Code is a voluntary code it becomes mandatory when adopted as part of a building regulation. Health care facilities are also affected by other codes which may significantly affect the cost impacts of the Life Safety Code. For a brief discussion of this topic see Joseph G. Sprague, "Common Sense Approach Needed in Dealing with Safety," Hospitals, Vol. 51, February 1, 1977, pp. 67-75.

[3] The term acceptable is placed in parentheses since recent studies have claimed that the costs of strict compliance to the Life Safety Code are greater than those which society is willing to bear.

document be performed in order to ensure that it was appropriate and adequate for legal use. The present Life Safety Code is aimed at addressing this need. It is revised every three years to reflect advances in fire and building technology (such as the methodology for identifying equivalent levels of fire safety[1]). Prior to any examining of the equivalency methodology, it may be instructive first to review several portions of the Life Safety Code. This will provide a framework which will facilitate the derivation of the equivalency methodology from the code.

As mentioned in Chapter 1, the Life Safety Code provides fixed solutions to life safety in designated occupancies. In this report particular emphasis will be placed on Chapter 10 of NFPA 101-1973 which is concerned with health care facilities. (New health care facilities are treated in Section 10-1; existing health care facilities[2] are treated in Section 10-2.) The technical foundations for the requirements outlined in Chapter 10 of NFPA 101 are concerned with three broad classes of fire safety, namely:

(1) Means of Egress;
(2) Features of Fire Protection; and
(3) Building Service Equipment.

A brief examination of the key fire safety measures covered in these three broad classes is now in order. (In this section individual fire safety measures are enumerated. This enumeration provides both transition and background information which will be needed to introduce the equivalency methodology.) The Life Safety Code defines Means of Egress as follows:

> A means of egress is a continuous and unobstructed way of exit travel from any point in a building or structure to a public way and consists of 3 separate and distinct parts: (a) the way of exit access, (b) the exit, and (c) the way of exit discharge.[3]

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[1] The equivalency methodology is the subject of the next two sections. The equivalency methodology discussed this report is based on the 1973 edition of the Life Safety Code. It is important to point out that activities are currently underway to incorporate the equivalency methodology into the 1980 edition of the Life Safety Code as a technology appendix.

[2] NFPA 101 defines an existing building as one already in existence when the code went into effect.

[3] Code for Safety to Life from Fire in Buildings and Structures, National Fire Protection Association, NFPA 101-1973, p. 101-16.

The general fire safety class "Means of Egress" includes: doors, interior and exterior stairs, horizontal exits,[1] ramps, exit passageways, escalators, fire escape stairs and ladders, and the illumination and marking of means of egress. The general fire safety class "Features of Fire Protection" includes: protection of vertical openings,[2] interior finishes, protective signaling systems, automatic sprinklers and other extinguishment equipment, segregation and protection of hazards, smoke partitions and fire doors. The general fire safety class "Building Service Equipment includes: air conditioning, ventilation, heating, cooking, and incineration.

In examining the preceding list it becomes apparent that the level of protection provided by some of the fire safety measures in one class of fire safety may affect and/or be affected by the level of other fire safety measures. In order to make this interdependence explicit, NFPA 101-1973 contains the following redundancy clause:

> The design of exits and other safeguards shall be such that reliance for safety to life in case of fire or other emergency will not depend solely on any single safeguard; additional safeguards shall be provided for life safety in case any single safeguard is ineffective due to some human or mechanical failure.[3]

The redundancy clause quoted above is thus of primary importance in any application of or modification to the Life Safety Code. Consequently any alternative solutions to the level of safety mandated by the Life Safety Code, such as those provided by the Center for Fire Research's equivalency methodology, also <u>must guarantee</u> that the level of fire safety provided is not dependent upon any <u>one</u> fire safety measure.

2.2 THE CONCEPT OF EQUIVALENCY

The core concept in the equivalency methodology is its treatment of fire safety in an individual fire zone of a health care facility. The term fire zone is defined as a space separated from all other spaces by floors, horizontal exits, or smoke barriers. (Where a floor is not subdivided by horizontal exits or smoke barriers the entire floor is the zone.) Three

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[1] NFPA 101 defines a horizontal exit as a way of passage from one building to an area of refuge in another building on approximately the same level, or a way of passage through or around a wall or partition to an area of refuge on approximately the same level in the same building, which affords safety from fire or smoke from the area of escape and areas communicating therewith.

[2] A vertical opening is an opening <u>through</u> a floor or roof.

[3] <u>Code for Safety to Life from Fire in Buildings and Structures</u>, National Fire Protection Association, NFPA 101-1973, p. 101-4.

basic classifications of fire safety are used in assessing the level of safety provided in a particular fire zone. These three classifications are:[1]

(1) Occupancy risk;[2]
(2) Building safety features;[3] and
(3) Safety redundancy.[4]

Associated with each of the first two fire safety classifications is a set of features subdivided into a set of parameters. For each parameter there is a descriptor which defines a state and a score which reflects the relative degree of risk or safety associated with that parameter. Through a series of manipulations involving these factors, it is possible to determine uniquely the level of safety provided within a particular fire zone. Each of the three basic fire safety classifications will now be examined in turn.

Occupancy Risk

The occupancy risk for a particular fire zone is assessed by evaluating the level of safety for each of the following five factors:

(1) Patient Mobility;
(2) Patient Density;
(3) Fire Zone Location
(4) Ratio of Patients to Attendants; and
(5) Patient Average Age.

A value, corresponding to the level of safety associated with each parameter, is obtained from a worksheet[5] and recorded. These values

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[1] Definitions for each safety classifications are taken from the report by Nelson and Shibe. H. E. Nelson and A. J. Shibe, A System for Fire Safety Evaluation of Health Care Facilities, National Bureau of Standards, NBSIR 78-1555, November 1978.

[2] Occupancy risk reflects the number of people affected by a given fire, the level of fire they are likely to encounter, and their ability to protect themselves.

[3] Building safety features reflect the ability of the building and its fire protection systems to provide measures of safety commensurate with the risk.

[4] Safety redundancy is a measure of the depth of protection. Its purpose is to insure that the failure of a single protection device or method will not result in a major failure of the entire system.

[5] A detailed example is worked out in the next section (see Table 1 of the worksheet presented as Exhibit 2.2 in Section 2.3).

when multiplied together[1] produce an occupancy risk factor. The occupancy risk factor is then adjusted to reflect whether the building is new or existing.[2]

Building Safety Features

The building safety features for the fire zone are assessed by evaluating the level of safety for each of the following 13 factors:

(1) Construction Type;
(2) Interior Finish: Corridors and Exits;
(3) Interior Finish: Rooms;
(4) Corridor Partition Walls;
(5) Doors to the Corridor;
(6) Zone Dimensions
(7) Vertical Openings;
(8) Hazardous Areas;
(9) Smoke Control;
(10) Emergency Movement Routes;
(11) Manual Fire Alarms;
(12) Automatic Detection and Alarm; and
(13) Sprinklers.

A value, corresponding to the level of safety associated with each parameter, is then taken from the second page of the worksheet[3] and and recorded.

Safety Redundancy

In the discussion of the Life Safety Code in Chapter 1, it was stated that the redundancy clause played a crucial role in identifying acceptable levels of fire safety. This issue is addressed in the equivalency methodology through the use of a four-way safety redundancy. The four safety categories are:

(1) Containment safety;
(2) Extinguishment safety;
(3) People movement safety; and
(4) General safety.

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[1] See Table 2 in Exhibit 2.2 in the next section.

[2] See Tables 3A and 3B of the worksheet presented as Exhibit 2.2 of Section 2.3.

[3] A detailed example is worked out in the next section (see Table 4 of the worksheet presented as Exhibit 2.4 in Section 2.3).

Safety redundance is evaluated by entering the value which corresponds to the level of safety associated with each of the 13 Building Safety Features in the appropriate places on page three of the worksheet.[1] These values are then summed to get a safety score. (The worksheet is designed so that one score results for each of the four safety redundancy categories.) Each of these scores are then entered on the fourth and final page of the worksheet.[2]

Equivalency to the Life Safety Code may then be tested by entering the scores associated with the mandatory safety requirements for containment safety, extinguishment safety, people movement safety[3] and the occupancy risk factor in the space provided on the worksheet. If the differences in the two sets of scores are nonnegative in all four cases, then the fire zone is deemed to be in compliance with the Life Safety Code. Note that the safety redundancy clause of the Life Safety Code requires that the minimum level of safety be met or exceeded for each of the four safety categories.

2.3 THE FIRE SAFETY EVALUATION SYSTEM

The purpose of this section is to show how the underlying concepts which went into the formulation of the equivalency methodology come together in the fire zone safety evaluation worksheet. The basic framework of the equivalency methodology is illustrated in Exhibits 2.1 through 2.9. Four of these exhibits, 2.1, 2.3, 2.5, and 2.7, form the Fire Zone Safety Evaluation Worksheet. The other five exhibits are examples of completed worksheets. Each of the first seven exhibits, Exhibit 2.1 through 2.7, contain two parts. Part A of each exhibit is a sample worksheet. Part B consists of a brief description of the worksheet.

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[1] A detailed example is worked out in the next section (see Table 5 of the worksheet presented as Exhibit 2.6 in Section 2.3).

[2] A detailed example is worked out in the next section (see Table 7 of the worksheet presented as Exhibit 2.9 in Section 2.3).

[3] These values are given in Table 6 of the worksheet presented as Exhibit 2.9 in Section 2.3).

EXHIBIT 2.1 SAMPLE WOKSHEET: METHODOLOGY FOR CALCULATING OCCUPANCY RISK FACTOR

PART A: WORKSHEET

Table 1. OCCUPANCY RISK PARAMETER FACTORS

RISK PARAMETERS — **RISK FACTOR VALUES**

1. PATIENT MOBILITY (M)

MOBILITY STATUS	MOBILE	LIMITED MOBILITY	NOT MOBILE	NOT MOVABLE
RISK FACTOR	1.0	1.6	3.2	4.5

2. PATIENT DENSITY (D)

PATIENT	1-5	6-10	11-30	>30
RISK FACTOR	1.0	1.2	1.5	2.0

3. ZONE LOCATION (L)

FLOOR	1ST	2ND OR 3RD	4TH TO 6TH	7TH AND ABOVE	BASE-MENTS
RISK FACTOR	1.1	1.2	1.4	1.6	1.6

4. RATIO OF PATIENTS TO ATTENDANTS (T)

PATIENTS / ATTENDANT	1-2 / 1	3-5 / 1	6-10 / 1	>11 / 1	ONE OR* MORE / NONE
RISK FACTOR	1.0	1.1	1.2	1.5	4.0

5. PATIENT AVERAGE AGE (A)

AGE	UNDER 65 YEARS AND OVER 1 YEAR	65 YEARS & OVER 1 YEAR & YOUNGER
RISK FACTOR	1.0	1.2

* RISK FACTOR OF 4.0 IS CHARGED TO ANY ZONE THAT HOUSES PATIENTS WITHOUT ANY STAFF IN IMMEDIATE ATTENDANCE

Table 2. OCCUPANCY RISK FACTOR CALCULATION

OCCUPANCY RISK: M ☐ × D ☐ × L ☐ × T ☐ × A ☐ = F ☐

Table 3A. (NEW BUILDINGS)

1.0 × F ☐ = R ☐

Table 3B. (EXISTING BUILDINGS)

0.5 × F ☐ = R ☐

EXHIBIT 2.1 SAMPLE WORKSHEET: METHODOLOGY FOR CALCULATING OCCUPANCY RISK FACTOR

PART B: DESCRIPTION

Table 1

Table 1 of the worksheet provides the values for each risk parameter. Based on the guidelines given in the NBS report by Nelson and Shibe[1] the appropriate value for each of the five risk parameters is then determined.

Table 2

The values identified in Table 1 are then entered in the spaces coded M, D, L, T and A. These values are multiplied together and entered in the space coded as F. The score recorded in box F is the "unadjusted" occupancy risk factor.

Table 3

The "unadjusted" occupancy risk factor calculated in Table 2 is then entered in either Table 3A or 3B. In the event that the building was constructed after the 1973 Life Safety Code went into effect, Table 3A should be used. The Occupancy Risk Factor is then defined as the product of the "unadjusted" occupancy risk factor and the Table 3A weighting factor of 1.0. If the building was constructed before the 1973 Life Safety Code went into effect, Table 3B should be used. In this case the Occupancy Risk Factor is defined as the product of the "unadjusted" occupancy risk factor and the Table 3B weighting factor of 0.5.

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[1] Harold E. Nelson and A. J. Shibe, A System for Fire Safety Evaluation of Health Care Facilities, National Bureau of Standards, NBSIR 78-1555, November 1978.

EXHIBIT 2.2 SAMPLE EVALUATION: FIRE ZONE IDENTIFICATION AND CALCULATION OF OCCUPANCY RISK FACTOR

PART A: WORKSHEET

Table 1. OCCUPANCY RISK PARAMETER FACTORS

RISK PARAMETERS — RISK FACTOR VALUES

1. PATIENT MOBILITY (M)

MOBILITY STATUS	MOBILE	LIMITED MOBILITY	NOT MOBILE	NOT MOVABLE
RISK FACTOR	1.0	1.6	(3.2)	4.5

2. PATIENT DENSITY (D)

PATIENT	1-5	6-10	11-30	>30
RISK FACTOR	1.0	1.2	1.5	(2.0)

3. ZONE LOCATION (L)

FLOOR	1ST	2ND OR 3RD	4TH TO 6TH	7TH AND ABOVE	BASEMENTS
RISK FACTOR	1.1	(1.2)	1.4	1.6	1.6

4. RATIO OF PATIENTS TO ATTENDANTS (T)

PATIENTS / ATTENDANT	1-2 / 1	3-5 / 1	6-10 / 1	>11 / 1	ONE OR* MORE / NONE
RISK FACTOR	1.0	1.1	(1.2)	1.5	4.0

5. PATIENT AVERAGE AGE (A)

AGE	UNDER 65 YEARS AND OVER 1 YEAR	65 YEARS & OVER 1 YEAR & YOUNGER
RISK FACTOR	(1.0)	1.2

* RISK FACTOR OF 4.0 IS CHARGED TO ANY ZONE THAT HOUSES PATIENTS WITHOUT ANY STAFF IN IMMEDIATE ATTENDANCE

Table 2. OCCUPANCY RISK FACTOR CALCULATION

	M		D		L		T		A		F
OCCUPANCY RISK	3.2	×	2.0	×	1.2	×	1.2	×	1.0	=	10

Table 3A. (NEW BUILDINGS)

	F		R
1.0^x		=	

Table 3B. (EXISTING BUILDINGS)

	F		R
0.5^x	10	=	5

EXHIBIT 2.2 SAMPLE EVALUATION: FIRE ZONE IDENTIFICATION AND CALCULATION OF OCCUPANCY RISK FACTOR

PART B: DESCRIPTION

Exhibit 2.2, Part A, provides an example of how the occupancy risk factor calculations are performed.

Table 1

The third floor fire zone, contains a staff of 5 attendants and 32 patients. Most of the patients in the zone are capable of removing themselves from danger by their own efforts, their rate of travel, however, is significantly less than that of a normal person. In addition, several patients are not mobile. The appropriate parameter for this factor is thus Not Mobile; it carries a charge of 3.2. (In calculating occupancy risk higher charges indicate higher risks.) The risk parameters associated with each of the other four factors in Table 1 are: Patient Density, 2.0, since there are more than 30 patients; Fire Zone Location, 1.2, since the fire zone is on the third floor; Ratio of Patients to Attendants, 1.2, since there are 6.4 patients per attendant; Patient Average Age, 1.0, since the average age is between 1 and 65.

Table 2

The "unadjusted" occupancy risk factor is calculated in Table 2 of Exhibit 2.2. If the answer is not an integer, as in this case, it is rounded up. The "unadjusted" occupancy risk factor in this case is 10.

Table 3

The "unadjusted" occupancy risk factor, 10, is next entered in Table 3B (Existing Buildings). The adjusted Occupancy Risk Factor which will be used in the evaluation is 5. Thus in order to satisfy the safety redundancy requirement for general safety, fire safety measures within the zone must produce at least 5 points under the general safety category.

EXHIBIT 2.3 SAMPLE WORKSHEET: VALUES OF SAFETY PARAMETERS AS A FUNCTION OF THE LEVEL OF SAFETY PROVIDED

PART A: WORKSHEET

Table 4. SAFETY PARAMETERS VALUES

PARAMETERS		PARAMETERS VALUES						
1. CONSTRUCTION		COMBUSTIBLE				NON-COMBUSTIBLE		
		WOOD FRAME		ORDINARY				
FLOOR OF ZONE		UNPROTECTED	PROTECTED	UNPROTECTED	PROTECTED	UNPROTECTED	PROTECTED	FIRE RESIST.
	FIRST	−2	0	−2	0	0	[illegible]	2
	SECOND	−7	−2	−4	−2	−2	2	4
	THIRD	−9	−7	−9	−7	−9	2	4
	4TH & ABOVE	−13	−7	−13	−7	−9	−7	4

PARAMETERS	PARAMETERS VALUES				
2. INTERIOR FINISH (Corr. & Exit)	CLASS C	CLASS B	CLASS A		
	−5	0	3		
3. INTERIOR FINISH (Rooms)	CLASS C	CLASS B	CLASS B		
	−3	3	3		
4. CORRIDOR PARTITIONS/WALLS	NONE OR INCOMPLETE	<1/3 HR	>1/3 <1.0 HR	≥1.0 HR.	
	−10 (0)*	0	1 (0)*	2 (0)*	
5. DOORS TO CORRIDOR	NO DOOR	<20 MIN.FR	>20 MIN. FR	>20 MIN. FR & AUTO CLOS.	
	−10	0	1 (0)***	2 (0)***	
6. ZONE DIMENSIONS	DEAD END MORE THAN 100'	DEAD END 30'–100'	NO DEAD ENDS>30' & ZONE LENGTH IS:		
			>150'	100'–150'	<100'
	−6 (0)**	−4 (0)**	−2	0	1
7. VERTICAL OPENINGS	OPEN 4 OR MORE FLOORS	OPEN 2 OR 3 FLOORS	ENCLOSED WITH INDICATED FIRE RESIST.		
			<1 HR.	≥1HR.<2 HR.	≥2 HR.
	−14	−10	0	2 (0)*	3 (0)*
8. HAZARDOUS AREAS	DOUBLE DEFICIENCY		SINGLE DEFICIENCY		NO DEFICIENCIES
	IN ZONE	OUTSIDE ZONE	IN ZONE	IN ADJACENT ZONE	
	−11	−5	−6	−2	0
9. SMOKE CONTROL	NO CONTROL	SMOKE PARTITION	MECH. ASSISTED SYSTEMS		
			BY ZONE	BY CORRIDOR	
	−2 (0)***	0	3	4	
10. EMERGENCY MOVEMENT ROUTES	<2 ROUTES	MULTIPLE ROUTES			
		DEFICIENT CAPACITY	W/O HORIZONTAL EXIT(s)	HORIZONTAL EXIT(s)	DIRECT EXIT(s)
	−8	−2	0	3	5
11. MANUAL FIRE ALARM	NO MANUAL FIRE ALARM		MANUAL FIRE ALARM		
			W/O F.D. CONN.	W/F.D. CONN.	
	−4		1	2	
12. SMOKE DETECTION & ALARM	NONE	CORRIDOR ONLY	ROOMS ONLY	CORRIDOR & HABIT. SPACE	TOTAL SPACE
	0	2	3	4	5
13. AUTOMATIC SPRINKLERS	NONE	CORRIDOR	CORRIDOR & HABIT. SPACE	TOTAL SPACE	
	0	2 (0)**	8	10	

NOTE: *Use (0) when item 5 is −10.
**Use (0) when item 10 is −8.
***Use (0) in zone with less than 31 patients in existing buildings.

*Use (0) when item 1 is based on first floor zone or on an unprotected type of construction.
**Use (0) when item 1 is based on an unprotected type of construction.
***Use (0) when item 4 is −10.

EXHIBIT 2.3 SAMPLE WORKSHEET: VALUES OF SAFETY PARAMETERS AS A FUNCTION OF THE LEVEL OF SAFETY PROVIDED

PART B: DESCRIPTION

Table 4

Table 4 of the Fire Zone Safety Evaluation Worksheet is presented in Part A of Exhibit 2.3. Each of the 13 Building Safety Features are listed in this exhibit. In addition to the listing, a value is given for each level of fire safety (parameter). A brief description of the level associated with each safety parameter is also given in a small box immediately above each parameter value. For example, the safety parameters for interior finishes in corridors and exits have a value of -5 for Class C finishes, a value of 0 for Class B finishes, and a value of 3 for Class A finishes.[1]

Specifications which enable the evaluator to determine the appropriate level to check for each building safety parameter are given by Nelson and Shibe.[2]

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[1] In this case the descriptors are Class C, Class B and Class A, respectively.

[2] H. E. Nelson and A. J. Shibe, A System for Fire Safety Evaluation of Health Care Facilities, National Bureau of Standards, NBSIR 78-1555, November 1978.

EXHIBIT 2.4 SAMPLE EVALUATION: VALUES OF SAFETY PARAMETERS FOR THE INITIAL STATE OF THE FIRE ZONE

PART A: WORKSHEET

Table 4. SAFETY PARAMETERS VALUES

PARAMETERS		PARAMETERS VALUES						
1. CONSTRUCTION		COMBUSTIBLE				NON-COMBUSTIBLE		
		WOOD FRAME		ORDINARY				
FLOOR OF ZONE		UNPROTECTED	PROTECTED	UNPROTECTED	PROTECTED	UNPROTECTED	PROTECTED	FIRE RESIST.
	FIRST	−2	0	−2	0	0	[illegible]	2
	SECOND	−7	−7	−7	−7	−7	2	4
	THIRD	−9	−7	−7	−7	−7	2	4
	4TH & ABOVE	−13	−7	−13	−7	−9	−7	4

PARAMETERS					
2. INTERIOR FINISH (Corr. & Exit)	CLASS C	CLASS B	CLASS A		
	−5	0	3		
3. INTERIOR FINISH (Rooms)	CLASS C	CLASS B	CLASS A		
	−3	1	3		
4. CORRIDOR PARTITIONS/WALLS	NONE OR INCOMPLETE	<1/3 HR	>1/3 <1.0 HR	≥1.0 HR.	
	−10 (0)*	0	1 (0)*	2 (0)*	
5. DOORS TO CORRIDOR	NO DOOR	<20 MIN.FR	>20 MIN. FR	>20 MIN. FR & AUTO CLOS.	
	−10	0	1 (0)***	2 (0)***	
6. ZONE DIMENSIONS	DEAD END MORE THAN 100'	DEAD END 30'–100'	NO DEAD ENDS>30' & ZONE LENGTH IS:		
			>150'	100'–150'	<100'
	−6 (0)**	−4 (0)**	−2	0	1
7. VERTICAL OPENINGS	OPEN 4 OR MORE FLOORS	OPEN 2 OR 3 FLOORS	ENCLOSED WITH INDICATED FIRE RESIST.		
			<1 HR.	≥1HR.<2 HR.	≥2 HR.
	−14	−10	0	2 (0)*	3 (0)*
8. HAZARDOUS AREAS	DOUBLE DEFICIENCY		SINGLE DEFICIENCY		NO DEFICIENCIES
	IN ZONE	OUTSIDE ZONE	IN ZONE	IN ADJACENT ZONE	
	−11	−5	−6	−2	0
9. SMOKE CONTROL	NO CONTROL	SMOKE PARTITION	MECH. ASSISTED SYSTEMS		
			BY ZONE	BY CORRIDOR	
	−2 (0)***	0	3	4	
10. EMERGENCY MOVEMENT ROUTES	<2 ROUTES	MULTIPLE ROUTES			
		DEFICIENT CAPACITY	W/O HORIZONTAL EXIT(s)	HORIZONTAL EXIT(s)	DIRECT EXIT(s)
	−8	−2	0	3	5
11. MANUAL FIRE ALARM	NO MANUAL FIRE ALARM		MANUAL FIRE ALARM		
			W/O F.D. CONN.	W/F.D. CONN.	
	−4		1	2	
12. SMOKE DETECTION & ALARM	NONE	CORRIDOR ONLY	ROOMS ONLY	CORRIDOR & HABIT. SPACE	TOTAL SPACE
	0	2	3	4	5
13. AUTOMATIC SPRINKLERS	NONE	CORRIDOR	CORRIDOR & HABIT. SPACE	TOTAL SPACE	
	0	2 (0)**	8	10	

NOTE:
- *Use (0) when item 5 is −10.
- **Use (0) when item 10 is −8.
- ***Use (0) in zone with less than 31 patients in existing buildings.

- *Use (0) when item 1 is based on first floor zone or on an unprotected type of construction.
- **Use (0) when item 1 is based on an unprotected type of construction.
- ***Use (0) when item 4 is −10.

EXHIBIT 2.4 SAMPLE EVALUATION: VALUES OF SAFETY PARAMETERS FOR THE INITIAL STATE OF THE FIRE ZONE

PART B: DESCRIPTION

Table 4

Part A of Exhibit 2.4 is an example of what a worksheet which has been filled out would be like. This worksheet is a continuation of the same evaluation of the fire zone being examined earlier. By referring to the third row of entries associated with the first factor, Construction, it can be seen that the appropriate construction type is noncombustible and that the level of the factor is fire resistive. The score associated with the parameter Non-combustible -- Fire Resistive -- Third Floor is 4. Both categories of Interior Finish (Corridor and Exit, and Rooms) are Class C. The values of the safety parameters are thus -5 and -3 respectively. The time-rated fire resistance classification of partitions between patient use areas and the corridors is revealed to be less than 20 minutes resulting in a score of 0. Inasmuch as all patient room doors have ordinary glass lights and insufficient latching, a no door charge is levied.[1] The score associated with this charge is -10. Since the fire zone contains a dead end greater than 30 feet but less than 100 feet, the score associated with the corridor length safety factor is -4. The fire zone contains three exit stairwells which have fire doors with a time-rated fire resistance classification of less than 1 hour. The score associated with this parameter is 0. Since the fire zone contains a high hazard area (e.g., soiled linen room) which is neither sprinklered nor protected by a fire resistive enclosure, the maximum charge, -11, is levied against the eighth safety factor. For the next safety factor, Smoke Control, the level of fire safety provided within the fire zone is minimal, resulting in a charge of -2. The fire zone contains multiple exit routes, three exit stairwells, and no horizontal exits. The score associated with the Emergency Movement Route factor is thus 0. The fire zone contains a manual fire alarm which is not connected to the fire department resulting in a score of 1 for the eleventh factor. The last two safety factors Automatic Detection and Alarm devices and Sprinklers are not provided within the fire zone resulting in a score of 0 in both cases.

It is important to point out that the safety parameters circled in Exhibit 2.4 reflect the current or initial state of the fire zone. That is, every level of safety accorded should actually be in place if the fire zone is in an existing building.

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[1] A room shall be considered as not having a door if there is (1) no door in the opening, (2) some mechanism which prevents closing of the door (3) insufficient latching to keep the door tightly closed, (4) a significant opening between the patient room and the corridor, or (5) within the door louvers or ordinary glass lights.

EXHIBIT 2.5 SAMPLE WORKSHEET: METHODOLOGY FOR EVALUATING THE LEVEL OF CONTAINMENT SAFETY, EXTINGUISHMENT SAFETY, PEOPLE MOVEMENT SAFETY, AND GENERAL SAFETY PROVIDED WITHIN THE FIRE ZONE

PART A: WORKSHEET

Table 5. **INDIVIDUAL SAFETY EVALUATIONS**

SAFETY PARAMETERS	CONTAINMENT SAFETY (S_1)	EXTINGUISHMENT SAFETY (S_2)	PEOPLE MOVEMENT SAFETY (S_3)	GENERAL SAFETY (S_G)
1. CONSTRUCTION				
2. INTERIOR FINISH (Corr. & Exit)				
3. INTERIOR FINISH (Rooms)				
4. CORRIDOR PARTITIONS/WALLS				
5. DOORS TO CORRIDOR				
6. ZONE DIMENSIONS				
7. VERTICAL OPENINGS				
8. HAZARDOUS AREAS				
9. SMOKE CONTROL				
10. EMERGENCY MOVEMENT ROUTES				
11. MANUAL FIRE ALARM				
12. SMOKE DETECTION & ALARM				
13. AUTOMATIC SPRINKLERS			÷ 2 =	
TOTAL VALUE	$S_1 =$	$S_2 =$	$S_3 =$	$S_G =$

EXHIBIT 2.5 SAMPLE WORKSHEET: METHODOLOGY FOR EVALUATING THE LEVEL OF CONTAINMENT SAFETY, EXTINGUISHMENT SAFETY, PEOPLE MOVEMENT SAFETY, AND GENERAL SAFETY PROVIDED WITHIN THE FIRE ZONE

PART B: DESCRIPTION

Table 5

Table 5 provides a means for calculating the scores associated with containment safety, extinguishment safety, people movement safety and general safety. These scores are then compared to the scores required by the 1973 Life Safety Code. The calculation is accomplished by entering the score associated with the appropriate parameter (state) for each Building Safety Feature in the light blocks of each row of the table. No values are entered in the shaded blocks. Each of the four columns is then summed to get the score for containment, extinguishment, people movement, and general safety. These scores are labeled S_1, S_2, S_3 and S_G respectively in Table 5.

EXHIBIT 2.6 SAMPLE EVALUATION: CURRENT LEVEL OF CONTAINMENT SAFETY, EXTINGUISHMENT SAFETY, PEOPLE MOVEMENT SAFETY, AND GENERAL SAFETY PROVIDED WITHIN THE FIRE ZONE

PART A: WORKSHEET

Table 5. INDIVIDUAL SAFETY EVALUATIONS

SAFETY PARAMETERS	CONTAINMENT SAFETY (S_1)	EXTINGUISHMENT SAFETY (S_2)	PEOPLE MOVEMENT SAFETY (S_3)	GENERAL SAFETY (S_G)
1. CONSTRUCTION	4	4		4
2. INTERIOR FINISH (Corr. & Exit)	-5		-5	-5
3. INTERIOR FINISH (Rooms)	-3			-3
4. CORRIDOR PARTITIONS/WALLS	0			0
5. DOORS TO CORRIDOR	-10		-10	-10
6. ZONE DIMENSIONS			-4	-4
7. VERTICAL OPENINGS	0		0	0
8. HAZARDOUS AREAS	-11	-11		-11
9. SMOKE CONTROL			-2	-2
10. EMERGENCY MOVEMENT ROUTES			0	0
11. MANUAL FIRE ALARM		[illegible]		1
12. SMOKE DETECTION & ALARM		0	0	0
13. AUTOMATIC SPRINKLERS	0	0	0 ÷ 2 = 0	1
TOTAL VALUE	S_1 = -25	S_2 = -6	S_3 = -21	S_G = -30

EXHIBIT 2.6 SAMPLE EVALUATION: CURRENT LEVEL OF CONTAINMENT SAFETY, EXTINGUISHMENT SAFETY, PEOPLE MOVEMENT SAFETY, AND GENERAL SAFETY PROVIDED WITHIN THE FIRE ZONE

PART B: DESCRIPTION

Table 5

Part A of Exhibit 2.6 shows what a completed Table 5 would look like. Notice that the first row, corresponding to the first Building Safety Feature (Construction) does not have an entry in the third column (people movement safety). This is because the type of construction in the fire zone does not affect the way people move through the fire zone, whereas it does affect the ability to contain or extinguish a potential fire within the fire zone as well as the overall occupancy risk. Similar observations can be made for other Building Safety Features (rows of Table 5) and for other safety requirements (columns of Table 5). In fact, only one safety requirement, general safety, is a function of all 13 Building Safety Features. Note also that the full score associated with sprinklers may not be claimed under people movement safety. This is because sprinklers when activated may limit the ability of the fire zone's occupants to seek refuge.

From Part A of Exhibit 2.6 it can be seen that the levels of safety being provided by the fire zone in its current state are: S_1, -25 points; S_2, - 6 points; S_3, -21 points; and S_G, -30 points.

EXHIBIT 2.7 SAMPLE WORKSHEET: METHODOLOGY FOR DETERMINING IF THE LEVEL OF SAFETY PROVIDED WITHIN THE FIRE ZONE IS EQUIVALENT TO THAT REQUIRED BY THE LIFE SAFETY CODE

PART A: WORKSHEET

Table 6. MANDATORY SAFETY REQUIREMENTS

	CONTAINMENT S_a		EXTINGUISHMENT S_b		PEOPLE MOVEMENT S_c	
ZONE LOCATION	New	Exist.	New	Exist.	New	Exist.
FIRST FLOOR	9.0	4.0	6.0	3.0	6.0	1.0
ABOVE FIRST FLOOR	14.0	8.0	8.0	5.0	9.0	3.0

Table 7. ZONE SAFETY EQUIVALENCY EVALUATION

					YES	NO
CONTAINMENT SAFETY (S_1)	less	MANDATORY CONTAINMENT (S_a)	≥0	S_1 [ ] − S_a [ ] = C [ ]		
EXTINGUISHMENT SAFETY (S_2)	less	MANDATORY EXTINGUISHMENT (S_b)	≥0	S_2 [ ] − S_b [ ] = E [ ]		
PEOPLE MOVEMENT SAFETY (S_3)	less	MANDATORY PEOPLE MOVEMENT (S_c)	≥0	S_3 [ ] − S_c [ ] = P [ ]		
GENERAL SAFETY (S_G)	less	OCCUPANCY RISK (R)	≥0	S_G [ ] − R [ ] = G [ ]		

EXHIBIT 2.7 SAMPLE WORKSHEET: METHODOLOGY FOR DETERMINING IF THE LEVEL OF SAFETY PROVIDED WITHIN THE FIRE ZONE IS EQUIVALENT TO THAT REQUIRED BY THE LIFE SAFETY CODE

PART B: DESCRIPTION

Part A of Exhibit 2.7 provides the means for determining if the fire zone possesses a level of fire safety equivalent to that of the 1973 Life Safety Code. Basically this is done by taking the four scores calculated in Table 5 and entering them in the boxes labeled S_1, S_2, S_3, and S_G in Table 7. The user then selects the values from Table 6 for containment safety, extinguishment safety, and people movement safety for the appropriate building type and fire zone location. These values are entered in the boxes labeled S_a, S_b, and S_c in Table 7. The Occupancy Risk Factor calculated on the first worksheet[1] is then entered in the box labeled R. Based on these two sets of numbers it is possible to test if the fire zone possesses a level of safety equivalent to the Life Safety Code. This test is performed by determining if the differences between the first set of numbers, S_1, S_2, S_3, and S_G, and the second set of numbers S_a, S_b, S_c, and R, in Table 7 are greater than or equal to zero.

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[1] See Part A of Exhibit 2.2 for an example.

Putting Together a Retrofit Package

Given that the fire zone under examination fails all four of the basic safety categories, it is necessary to determine how compliance to the Life Safety Code may be achieved through renovation or retrofitting of the fire zone. However, in order to identify a potential retrofit strategy, all possible retrofits associated with each Building Safety Feature must be identified. This may be done by referring once again to Exhibit 2.4 where the initial state of the fire zone is presented. An examination of Exhibit 2.4 reveals that only the first Building Safety Feature (Construction), is already at the highest possible level (or state). (The highest possible level (or state) of fire safety for each feature is defined as the parameter with the highest score.) In the discussion which follows, the term state will be used to denote a given level of fire safety for each Building Safety Feature. For example, "No Door" is the lowest state for the Building Safety Feature Doors to Corridor, doors with less than a 20 minute fire rating is the second state, doors with more than a 20 minute fire rating is the third state, and doors with more than a 20 minute fire rating and automatic closers is the fourth and highest state.

Twelve Building Safety Features are left after ruling out the first feature which has been identified as already existing in the highest possible state. In each of these cases it is possible to move from the existing state to a higher state. These possibilities shall be denoted as potential retrofits. For example, potential retrofits for corridor partition walls are corridor partition walls with: (1) fire ratings of from 20 to 60 minutes; and (2) fire ratings of more than 60 minutes. Since the costs of each potential retrofit are ignored in the present discussion, the focus will be only on the changes in score associated with a potential retrofit; that is, the change in score in going from a lower state to a higher one.

One possible retrofit strategy would be to go to the highest possible state for each Building Safety Feature. Even if costs are ignored, such a strategy would not be efficient since the resulting score for each of the four safety redundancy requirements would far exceed the score needed to achieve compliance. For the fire zone evaluated in Exhibits 2.1 through 2.7, in order to meet the requirements of the Life Safety Code, the score would have to improve by 33 points for containment safety, 12 points for extinguishment safety, 24 points for people movement safety, and 35 points for general safety. Although more efficient means exist for selecting potential retrofits based on score improvements,[1] a simplistic approach which refers only to the information contained in Table 4 of the Fire Zone Safety Evaluation Worksheet presented in Part A of Exhibit 2.4 will be presented in this discussion.

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[1] See the report by Nelson and Shibe, A System for Fire Safety Evaluation of Health Care Facilities. It is important to point out that the computer program discussed in the report by Nelson and Shibe does not assess the cost of the alternative retrofits.

The greatest potential for score improvement exists in those Building Safety Features having the largest negative charges. These are: 2, Interior Finish: Corridor and Exits, -5; 3, Interior Finish: Rooms, -3; 5, Doors to the Corridor, -10; 6, Zone Dimensions, -4; and 8, Hazardous Areas, -11.

Net improvements of 8 points for Interior Finishes in Corridors and Exits and 6 points for Interior Finishes in Rooms can be achieved by reducing flame spread ratings from Class C to Class A. This retrofit can usually be accomplished by painting the surface with fire retardant paint, or in the case of paneling, treating it with a fire retardant finish. The -10 point charge for Doors to the Corridor is a strong indication that this factor should be upgraded. Note that in the presence of a "No Door" charge, no score improvement is possible for Corridor Partition Wall retrofits. This is due to an interdependency between the two features.[1]

In this case, replacing the ordinary glass lights in the patient room doors with wire glass lights and repairing the defective latches will upgrade all doors to a less than 20 minute fire rating. This will result in a net improvement of 10 points for the fifth feature (Doors to the Corridor) without changing the score for the fourth factor (Corridor Partition Walls). The removal of the dead end corridor is not a very attractive retrofit since it would require the installation of an exit stairwell. An attractive retrofit not mentioned earlier is the upgrading of the fire rating on the three exit fire doors from less than 1 hour to more than 2 hours. This retrofit accounts for a 3 point net improvement in the seventh feature, Verical Openings. The next candidate for retrofitting is the eighth feature, Hazardous Areas. The removal of all deficiencies may be accomplished by installing sprinklers in all hazardous areas and upgrading the enclosure of high hazard areas to fire resistive.[2]

The last retrofit considered is the installation of a horizontal exit. This retrofit is attractive because it results in a score improvement of 3 points in the tenth feature, Emergency Movement Routes, and a score

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[1] The interdependency is most serious when both features are in the lowest state. In such a case, if the doors to the corridor are upgraded, the score for the corridor partition walls will change from 0 to -10 points. By the same token no score improvement would be possible for upgrading corridor partition walls as long as the "No Door" charge remains in effect. Consequently this interdependency must be addressed in the development of a retrofit strategy when both features are in the lowest state. In this worst case scenario, the score interdependence is removed as long as the retrofit strategy includes improvements for <u>both</u> doors and corridor partition walls.

[2] It is assumed that any hazardous areas on other floors are separated from the hazardous area(s) under consideration by 1-hour fire resistive rated construction.

improvement of 2 points in the ninth feature, Smoke Control, since a horizontal exit can also be counted as a smoke partition.[1]

It is now necessary to determine if the retrofit strategy outlined above will provide a level of safety equivalent to that required by the Life Safety Code. The retrofit strategy is summarized in Table 2.1.

Table 2.1 Hypothetical Retrofit Strategy

Building Safety Feature	Retrofit
Interior Finish Corridor and Exits Rooms	Reduce flame spread rating from Class C to Class A.
Doors to the Corridor	Upgrade fire rating to less than 20 minutes
Vertical Openings	Upgrade fire rating on fire doors to more than 2 hours.
Hazardous Areas	Install sprinklers in all hazardous areas. Ensure a fire resistive enclosure for all high hazard areas.
Emergency Movement Routes	Install a horizontal exit
Smoke Control	Smoke partition is automatically credited due to the installation of a horizontal exit.

The scores associated with the (new) state of each safety parameter for the hypothetical retrofit strategy are now entered in the appropriate blocks in Table 5 of the Fire Zone Safety Evaluation Worksheet shown in Exhibit 2.8. The score for each safety category is then computed by summing the values in each column. In this case the scores for each safety category are: containment safety, 13 points; extinguishment safety, 5 points; people movement safety, 5 points; and general safety, 13 points. In Exhibit 2.9 these scores are compared to those required by the Life Safety Code. This examination reveals that the hypothetical retrofit strategy satisfies the Life Safety Code, since for each of the four safety redundancy requirements the post retrofit score matches or

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[1] A horizontal exit can only be credited if at least 30 net square feet per institutional occupant is provided for the <u>total</u> number of institutional occupants in adjoining compartments. If the zone were the entire floor, then the horizontal exit would have to divide the floor in such a way that on either side of the horizontal exit all patients and staff could seek refuge and have at least 30 net square feet per person.

EXHIBIT 2.8 SAMPLE EVALUATION: POST RETROFIT LEVEL OF CONTAINMENT SAFETY, EXTINGUISHMENT SAFETY, PEOPLE MOVEMENT SAFETY, AND GENERAL SAFETY PROVIDED WITHIN THE FIRE ZONE

Table 5. INDIVIDUAL SAFETY EVALUATIONS

SAFETY PARAMETERS	CONTAINMENT SAFETY (S_1)	EXTINGUISHMENT SAFETY (S_2)	PEOPLE MOVEMENT SAFETY (S_3)	GENERAL SAFETY (S_G)
1. CONSTRUCTION	4	4		4
2. INTERIOR FINISH (Corr. & Exit)	3		3	3
3. INTERIOR FINISH (Rooms)	3			3
4. CORRIDOR PARTITIONS/WALLS	1			0
5. DOORS TO CORRIDOR	0		0	0
6. ZONE DIMENSIONS			-4	-4
7. VERTICAL OPENINGS	3		3	3
8. HAZARDOUS AREAS	3	0		0
9. SMOKE CONTROL			0	0
10. EMERGENCY MOVEMENT ROUTES			3	[illegible]
11. MANUAL FIRE ALARM		1		1
12. SMOKE DETECTION & ALARM		0	0	3
13. AUTOMATIC SPRINKLERS	1	0	0 ÷ 2 = 0	0
TOTAL VALUE	S_1 = 13	S_2 = 5	S_3 = 5	S_G = 13

EXHIBIT 2.9 SAMPLE EVALUATION: EVALUATION OF POST RETROFIT LEVEL OF SAFETY PROVIDED WITHIN THE FIRE ZONE TO DETERMINE IF IT IS EQUIVALENT TO THAT REQUIRED BY THE LIFE SAFETY CODE

Table 6. **MANDATORY SAFETY REQUIREMENTS**

	CONTAINMENT S_a		EXTINGUISHMENT S_b		PEOPLE MOVEMENT S_c	
ZONE LOCATION	New	Exist.	New	Exist.	New	Exist.
FIRST FLOOR	9.0	4.0	6.0	3.0	6.0	1.0
ABOVE FIRST FLOOR	14.0	8.0	8.0	5.0	9.0	3.0

Table 7. **ZONE SAFETY EQUIVALENCY EVALUATION**

					YES	NO
CONTAINMENT SAFETY (S_1)	less	MANDATORY CONTAINMENT (S_a)	≥0	S_1 13 − S_a 8 = C 5	√	
EXTINGUISHMENT SAFETY (S_2)	less	MANDATORY EXTINGUISHMENT (S_b)	≥0	S_2 5 − S_b 5 = E 0	√	
PEOPLE MOVEMENT SAFETY (S_3)	less	MANDATORY PEOPLE MOVEMENT (S_c)	≥0	S_3 5 − S_c 3 = P 2	√	
GENERAL SAFETY (S_G)	less	OCCUPANCY RISK (R)	≥0	S_G 13 − R 5 = G 8	√	

exceeds the score required by the Life Safety Code. Note, however, this analysis has not addressed the crucial issue of the costs of the hypothetical retrofit strategy. This issue will be introduced gradually beginning with the next section.

2.4 THE COSTS OF STRICT COMPLIANCE VERSUS EQUIVALENCY

The framework for determining the cost savings of the equivalency methodology over those associated with strict compliance will be developed in this section.

However, before the cost savings associated with the equivalency methodology can be quantified, two additional pieces of information are needed. The first is concerned with the units which must be used in reporting the required information on each of the 13 Building Safety Features. The second relates a unique parameter (state) for each of the 13 Building Safety Features in Table 4 of the Fire Zone Safety Evaluation Worksheet to strict compliance to the Life Safety Code. With these two pieces of information it is possible to use data on the unit cost of each element requiring treatment in order to calculate the total cost of each potential retrofit.[1] These costs may then be compared with those resulting from the strict compliance solution to determine the savings attributable to the equivalency methodology.

Data Requirements

In order to address the first issue a cost format patterned after Table 4 of the Fire Zone Safety Evalution Worksheet has been developed. This format is presented as Table 2.2. Notice that each of the 13 Building Safety Features is listed in Table 2.2. However, Table 2.2 differs from Table 4 of the Fire Zone Safety Evaluation Worksheet in one very important way. In every case the lowest possible state associated with a given feature has been eliminated. This was done because the scale of the job is a function of the number of elements requiring treatment in order to advance from the existing state to a higher state. Since moving from a higher state to a lower state[2] is not permitted, attention will be focused upon potential retrofits.

To better illustrate this approach and to make this rationale more transparent, two additional tables, Table 2.3 and 2.4, have been prepared. Table 2.3 identifies the abbreviations for the elements which appear in Table 2.4. Table 2.4 is identical to Table 2.2 with the exception that the elements and the units used to determine the scale of the job have

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[1] See Appendix A for a brief discussion of how the unit cost of each element associated with a potential retrofit was established.

[2] It is always possible to remain in the same state at zero cost.

Table 2.2 Required Information on Key Safety Parameters

Building Safety Feature	Parameter Descriptors			
1. Construction	Combustible: Wood Frame	Combustible: Ordinary	Non-combustible	
Floor	Protected	Protected	Protected	Fire Resistive
2. Interior Finish [Corr. & Exit]	Class B	Class A		
3. Interior Finish [Rooms]	Class B	Class A		
4. Corridor Partition Walls	<1/3 HR	1/3-1.0 HR	>1.0 HR	
5. Doors to Corridor	<20 min FR	>20 min FR	>20 Min. FR & Auto Closer	
6. Corridor Lengths	Dead End 30'-100'	No Dead Ends >30' & Corridor Length is >150	100-150	<100
7. Vertical Openings	Enclosed with Indicated Fire Resistance: <1 HR	>1 HR <2 HR	2 HR	
8. Hazardous Areas	Single Deficiency	No Deficiencies		
9. Smoke Control	Smoke Partition	Mech. Assisted Systems: Fire Zone	Mech. Assisted Systems: Corridor	
10. Emergency Movement	w/o Horizontal Exit(s)	Horizontal Exit(s)	Direct Exit(s)	
11. Manual Fire Alarm	Manual Fire Alarm: w/o FD Conn	Manual Fire Alarm: w/FD Conn		
12. Automatic Detection & Alarm	Corridor Only	Rooms Only	Corridor & Habit. Space	Total Space
13. Sprinklers	Corridor	Corridor & Habit. Space	Total Space	

Table 2.3 Abbreviations for Elements and Units to be Used in Reporting Data on Potential Retrofits

Abbreviation	Definition
$Ft^2(C)$	Square feet of construction to be protected (e.g., ceilings, walls, columns, or floors)
$Ft^2(F)$	Square feet of floor/ceiling area
$Ft^2(W)$	Square feet of wall area
Ft(P)	Linear feet of partition extended to the structural slab
D	Number of doors
D + F	Number of door and frame systems
O	Number of openings
C	Number of closers
FD	Number of fire doors
FD + F	Number of fire door and frame systems
CPFD + F	Number of corridor partitionings with fire door and frame systems
S	Number of stairwells
#	Number of any element/unit

Table 2.4 Elements and Units to be Used in Reporting Data on Potential Retrofits

Building Safety Feature	Parameter Descriptors			
1. CONSTRUCTION	Combustible: Wood Frame	Combustible: Ordinary	Non-combustible	
FLOOR	Protected	Protected	Protected	Fire Resistive
#	Ft^2(C)	Ft^2(C)	Ft^2(C)	Ft^2(C)
2. INTERIOR FINISH [Corr. & Exit]	Class B	Class A		
	Ft^2(F),Ft^2(W)	Ft^2(F),Ft^2(W)		
3. INTERIOR FINISH [Rooms]	Class B	Class A		
	Ft^2(F),Ft^2(W)	Ft^2(F),Ft^2(W)		
4. CORRIDOR PARTITION WALLS	<1/3 Hr	1/3-1.0 Hr	>1.0 Hr	
	Ft^2(W),O	Ft^2(W),O	Ft^2(W),O	
5. DOORS TO CORRIDOR	<20 min FR	>20 min FR	>20 min FR	
	D,D+F,O	D,D+F,O	D,D+F,O,C	
6. CORRIDOR LENGTHS	Dead End	No Dead Ends >30' & Corridor Length		Length is
	30'-100'	>150'	100'-150'	<100'
	S	S	S	S
7. VERTICAL OPENINGS	Enclosed with Indicated Fire Resistance: <1 HR	>1 HR <2 HR	2 HR	
	Ft^2(W),FD,FD+F	Ft^2(W),FD,FD+F	Ft^2(W),FD,FD+F	
8. HAZARDOUS AREAS	Single Deficiency	No Deficiencies		
	Ft^2(F), FT^2(W),FD,FD+F	Ft^2(F),Ft^2(W),FD,FD+F		
9. SMOKE CONTROL	Smoke Partition	Mechanically Assisted Systems: Fire Zone	Mechanically Assisted Systems: Corridor	
	Ft^2(W),CPF+D	#	#	
10. EMERGENCY MOVEMENT ROUTES	w/o Horizontal Exit[s]	Multiple Routes: Horizontal Exit[s]	Multiple Routes: Direct Exit[s]	
	#	Ft^2(W), Ft(P),CPF+D	#	
11. MANUAL FIRE ALARM	Manual Fire Alarm: w/o F.D. Conn	Manual Fire Alarm: w/F.D. Conn		
	#	#		
12. AUTOMATIC DETECTION & ALARM	Corridor Only	Rooms Only	Corridor & Habit. Space	Total Space
	Ft^2(F)	Ft^2(F)	Ft^2(F)	Ft^2(F)
13. SPRINKLERS	Corridor	Corridor & Habit. Space	Total Space	
	Ft^2(F)	Ft^2(F)	Ft^2(F)	

been filled in beneath each potential retrofit.[1] For example, suppose the fire zone was found to have 500 square feet of interior finish in the corridors and exits which had a fire rating of Class C (e.g., plywood paneling), and 500 square feet with Class B (e.g., ceiling tiles), all other areas being Class A. Then to upgrade that feature in the fire zone to Class B would require that the 500 square feet of interior finish with a Class C flame spread be treated. If the feature was to be upgraded to Class A then all 1,000 square feet in Class B and in Class C would have to be treated. That is, the row of Table 2.2 corresponding to the case just described when filled in would be:[2]

2. INTERIOR FINISH (Corr & Exit)	CLASS B 0,500	CLASS A 500,500

As can be seen from Table 2.4, the scale of the job is measured in the number of elements required to move to a higher state. For Building Safety Features 1 (Construction), 2 (Interior Finishes: Corridors and Exits), 3 (Interior Finishes: Rooms), 12 (Automatic Detection & Alarm), and 13 (Sprinklers[3]) the scale of the job is measured in terms of square

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[1] It is important to point out that the elements and units referenced in Table 2.3 and 2.4 are facility dependent. More specifically, they have been tailored to the typical hospital design analyzed in in Chapter 3. Additional research may conclude that certain health care facility types will require slightly different elements and units as inputs.

[2] In the case cited above the initial state for Building Safety Feature 2 was Class C. If the initial state were Class B, then the row of Table 2.2 would be:

2. INTERIOR FINISH (Corr & Exit)	CLASS B 0,0	CLASS A 500,0

Thus the only potential retrofit would be to go to Class A. We could of course remain in Class B at zero cost. If the initial state were Class A, then the row of Table 2.2 would be:

2. INTERIOR FINISH (Corr & Exit)	CLASS B 0,0	CLASS A 0,0

In this case no potential retrofits exist. Consequently, it is possible to remain in Class A at zero cost. In the above example the first entry corresponds to the square feet of floor area requiring treatment; the second entry corresponds to the square feet of wall area requiring treatment. This scheme was selected to facilitate data inputs into the computerized procedure discussed in Section 2.6.

[3] A fixed number of square feet per detector and sprinkler head is assumed for all calculations involving the installation of automatic detection and alarm and sprinkler systems.

feet treated. In this case square feet can be interpreted to mean either the square feet of floor/ceiling area or square feet of wall area requiring treatment. The fourth feature, Corridor Partition Walls, is slightly more complicated. It consists of a square feet of wall area count, denoted as $Ft^2(W)$, and a number of openings count, denoted as O. For Building Safety Features 5, 6 and 11 the count refers to the number of times that the element listed under each potential retrofit must be treated to move to that state. In these cases unit costs are per opening, per door, per door and frame system, and per automatic closer for Building Safety Feature 5. For Building Safety Feature 6 the unit cost is per dead end removed (stairwell installed). For the eleventh feature the unit cost is either per manual fire alarm installed or per connection to the fire department. The treatment of vertical openings is slightly more complicated because it requires information on both the square feet of surface requiring fireproofing, the number of fire doors installed, and the number of fire door and frame systems installed.

For example, if the fire zone contained 40 doors to the corridor and the no door charge was appropriate in 7 cases, due to ordinary glass lights, and all other doors have a fire rating of more than 20 minutes, line 5 of Table 2.2 would look like:

5. DOORS TO CORRIDOR	<20 MIN FR	>20 MIN FR	>20 MIN FR & AUTO CLOS
	0,0,7,0	0,0,7,0	0,0,7,40

In the event that all doors had a fire rating of 20 minutes or more, line 5 of Table 2.2 would look like:

5. DOORS TO CORRIDOR	<20 MIN FR	>20 MIN FR	>20 MIN FR & AUTO CLOS
	0,0,0,0	0,0,0,0	0,0,0,40

Three of the 13 Building Safety Features have still not been discussed. These features require special treatment since the units used in computing the scale of the job in moving from one state to another may change. Consider the smoke control safety feature (line 9 in Table 2.3). If there is presently no smoke control, three retrofits are possible: (1) a smoke partition, (2) mechanically assisted systems[1] by fire zone, and (3) mechanically assisted systems by corridor. Since the configuration of fire zones may vary within the facility, the cost of installing a smoke partition may also vary considerably. Thus the number of elements to be used in calculating the scale of the job is the number of square feet of wall area requiring fireproofing as well as the number

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[1] Mechanically assisted systems include a smoke partition as well as automatically controlled fans, smoke vent shafts, or a combination of the two.

of corridor partitioning systems which contain a fire door and frame that are installed. For mechanically assisted systems, however, the scale of the job is the number of automatically controlled fans or smoke vent shafts installed. Consequently, an adequate assessment of costs requires two measures.

The same problem results in the treatment of emergency movement routes. For this feature the installation of a horizontal exit is analogous to the installation of a smoke partition. (In fact the installation of a horizontal exit permits a smoke partition to be claimed under the smoke control safety feature.) Since layouts may vary from zone to zone it appears more efficient to record the costs of installing a horizontal exit on the basis of square feet of wall area requiring fireproofing, the linear feet of partition extended to the structural slab above, and the number of corridor partitioning systems which contain a fire door and frame that are installed. (The use of these measures permits greater flexibility in the use of the computerized procedure since unit costs remain constant over a wide range of job sizes.)

The last Building Safety Feature to be treated is the one dealing with hazardous areas. Hazardous area deficiencies may be removed through the installation of a fire resistive enclosure and/or an automatic sprinkler protection system. Four separate pieces of information are thus required to cover all cases. For example, the cost of a fire resistive enclosure depends upon the square feet of wall area, $Ft^2(W)$, which must be upgraded to a 2 hour fire rating and the number of fire doors, FD, or fire door and frame systems, FD+F, which must be installed. The costs of an automatic sprinkler protection system, however, depend on the square feet of floor area, $Ft^2(F)$, in the hazardous area.[1] A double deficiency may be reduced to a single deficiency through the installation of either a fire resistive enclosure or an automatic sprinkler system. To determine the least-cost solution, the scale of both potential retrofits must, therefore, be included. To move from a double deficiency to no deficiencies the installation of both a fire resistive enclosure and an automatic sprinkler protection system is required. To move from a single deficiency to no deficiencies in a high hazard area either an automatic sprinkler system or a fire resistive enclosure has already been installed, so the number of units for the system already in place should be recorded as zero. The appropriate figure(s) for the potential retrofit should then be entered either before or after the zero(es) depending on whether the hazardous area is enclosed or sprinklered. If the hazardous area is defined as ordinary, then either system may be used to remove the deficiency.

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[1] As in the earlier cases, the order in which the figures are entered is important. $Ft^2(F)$ should always be entered first; $Ft^2(W)$ second; the number of fire doors to be installed, FD, third; and the number of fire door and frame systems, FD+F, last.

The Prescriptive Requirements of the Life Safety Code

It is now time to address the second issue, the value of each Building Safety Feature which corresponds to strict compliance to the Life Safety Code. Tables 2.5 and 2.6 show the level of each safety feature which corresponds to strict compliance for all possible cases. Table 2.5 shows the level of each feature corresponding to strict compliance for health care facilities which are non-sprinklered. Table 2.6 shows the level of each feature corresponding to strict compliance for health care facilities which are totally sprinklered. Each table is then divided into a part for new buildings and a part for existing buildings. In all, eleven cases are presented in the two tables, four for non-sprinklered health care facilities and seven for sprinklered health care facilities.

The four non-sprinklered cases presented in Table 2.5 are analyzed first. For example, from Table 2.5 it can be seen that to determine the value (and level) of each safety parameter which corresponds to strict compliance for a new 1 story non-sprinklered health care facility, it would be necessary to refer to the first column of the table. The first column of Table 2.5 reveals that the construction type must be protected non-combustible in order to be in strict compliance to the Life Safety Code. Similarly, flame spread ratings for interior finishes are Class A for corridors and exits and Class B for rooms. Corridor partition walls should have a fire rating of at least 1 hour and all doors to the corridor should have a fire rating of at least 20 minutes. The corridors in the fire zone must not exceed 150 feet in length and have no dead ends greater than 30 feet in length. (No fixed solution for the treatment of vertical openings is prescribed by the Life Safety Code for this building type.) Continuing in the first column it should be noted that: no deficiencies are permitted for hazardous areas, smoke partitions are required within the fire zone to insure an adequate level of smoke control, and the fire zone must have multiple emergency movement routes. The eleventh and twelth rows of this column of Table 2.5 indicate that manual fire alarms with a fire department connection are required and that smoke detection and alarm devices are required in the corridors. (Recall that the facility is non-sprinklered so that the last safety parameter, automatic sprinklers, is listed as none.)

If the scores corresponding to the mandatory level of safety for each Building Safety Feature are summed, a total score of 13 points results. Note that the column sum corresponds to the score for general safety (Column 4 of Table 5 in the Fire Zone Safety Evaluation Worksheet). If the appropriate values from the first column in Table 2.5 are now entered onto Table 5 of the Fire Zone Safety Evaluation Worksheet (see Exhibit 2.5) one would find that the following score for each safety category results:

Containment safety	9 points
Extinguishment safety	6 points
People movement safety	6 points
General safety	13 points

Table 2.5 Values of Safety Parameters Corresponding to Strict Compliance to the Life Safety Code: Non-Sprinklered Facilities

BUILDING SAFETY FEATURE	BUILDING TYPE: NEW 1 STORY	NEW-MORE THAN 1 STORY	EXISTING 1 STORY	EXISTING MORE THAN 1 STORY
1. CONSTRUCTION	PROT. NON-COMB.	FIRE RESISTIVE	PROT. NON-COMB.	FIRE RESISTIVE
	2	4	2	4
2. INTERIOR FINISH [Corr. & Exit]	CLASS A	CLASS A	CLASS B	CLASS B
	3	3	0	0
3. INTERIOR FINISH [Rooms]	CLASS B	CLASS B	CLASS B	CLASS B
	1	1	1	1
4. CORRIDOR PARTITIONS/WALLS	> 1.0 HR	≥ 1.0	< 1/3 HR	< 1/3 HR
	2	2	0	0
5. DOORS TO CORRIDOR	> 20 Min	> 20 Min.	> 20 Min.	> 20 Min.
	1	1	1	1
6. ZONE DIMENSIONS[a]	100'-150'	100'-150'	100'-150'	100'-150'
	0	0	0	0
7. VERTICAL OPENINGS	Non-App.	2 HR	NotApp.	> 1- < 2 HR
	0	3	0	2
8. HAZARDOUS AREAS	No Deficiencies	No Deficiencies	No Deficiencies	No Deficiencies
	0	0	0	0
9. SMOKE CONTROL	Smoke Part.	Smoke Part.	Smoke Part.	Smoke Part.
	0	0	0	0
10. EMERGENCY MOVEMENT ROUTES	Multiple Routes	Multiple Routes	Multiple Routes	Multiple Routes
	0	0	0	0
11. MANUAL FIRE ALARM	W/FD Conn.	W/FD Conn.	W/O/FD Conn.	W/O/FD Conn.
	2	2	1	1
12. SMOKE DETECTION & ALARM	Corridor Only	Corridor Only	None	None
	2	2	0	0
13. AUTOMATIC SPRINKLERS	None	None	None	None
	0	0	0	0
TOTAL VALUE	13	18	5	9

[a] No dead ends greater than 30 feet and corridor length is as recorded.

Table 2.6 Values of Safety Parameters Corresponding to Strict Compliance to the Life Safety Code: Totally Sprinklered Facilities

SAFETY FACTOR	BUILDING TYPE						
	NEW - 1 STORY	NEW 2 AND 3 STORY	NEW-MORE THAN 3 STORIES	EXISTING 1 STORY	EXISTING 2 STORY	EXISTING 3 STORY	EXISTING MORE THAN 3 STORIES
1. CONSTRUCTION	PROTECT. COMB. 0	PROT. NON-COMB. 2	FIRE RESISTIVE 4	UNPROT. COMB. -2	PROT. COMB. -2	PROT. NON-COMB. 2	FIRE RESISTIVE 4
2. INTERIOR FINISH [Corr. & Exit]	CLASS B 3	CLASS A 3	CLASS A 3	CLASS B 0	CLASS B 0	CLASS B 0	CLASS B 0
3. INTERIOR FINISH [Rooms]	CLASS B 1	CLASS B 1	CLASS B 1	CLASS B 1	CLASS B 1	CLASS B 1	CLASS B 1
4. CORRIDOR PARTITIONS/WALLS	1/3 HR 0	< 1/3 HR 0	< 1/3 HR 0	< 1/3 HR 0	< 1/3 HR 0	< 1/3 HR 0	< 1/3 HR 0
5. DOORS TO CORRIDOR	20 Min. 0	< 20 Min. 0	< 20 Min. 0	< 20 Min. 0	< 20 Min. 0	< 20 Min. 0	< 20 Min. 0
6. ZONE DIMENSIONS[a]	> 150' -2	> 150' -2	150' -2	> 150' -2	> 150' -2	> 150' -2	> 150' -2
7. VERTICAL OPENINGS	Not App. 0	> 1- < 2 HR 2	2 HR 3	Not App. 0	> 1- < 2 HR 2	> 1- < 2 HR 2	> 1- < 2 HR 2
8. HAZARDOUS AREAS	No Deficiencies 0	No Deficiencies 0	No Deficiencies 0	No Deficiencies 0	No Deficiencies 0	No Deficiencies 0	No Deficiencies 0
9. SMOKE CONTROL	Smoke Part. 0	Smoke Part. 0	Smoke Part. 0	Smoke Part. 0	Smoke Part. 0	Smoke Part. 0	Smoke Part. 0
10. EMERGENCY MOVEMENT ROUTES	Multiple Routes 0	Multiple Routes 0	Multiple Routes 0	Multiple Routes 0	Multiple Routes 0	Multiple Routes 0	Multiple Routes 0
11. MANUAL FIRE ALARM	W/FD CONN. 2	W/FD Conn. 2	W/FD Conn. 2	W/O/FD Conn. 1	W/O/FD Conn. 1	W/O/FD Conn. 1	W/O/FD Conn. 1
12. SMOKE DETECTION & ALARM	Corridor Only 2	Corridor Only 2	Corridor Only 2	None 0	None 0	None 0	None 0
13. AUTOMATIC SPRINKLERS	Total Space 10	Total Space 10	Total Space 10	Total Space 10	Total Space 10	Total Space 10	Total Space 10
TOTAL VALUE	16	20	23	8	10	14	16

[a] No dead ends greater than 30 feet and corridor length is as recorded.

Note that the scores for the first three categories correspond to the values given as the mandatory safety requirements for a fire zone located on the first floor of a new health care facility in Table 6 of the Fire Zone Safety Evaluation Worksheet (see Exhibit 2.7 in the previous section). Recall that the level of safety associated with the general safety requirement was calculated separately using Tables 1 through 3 on the first page of the Fire Zone Safety Evaluation Worksheet. In some cases the score requirement would exceed that resulting from strict compliance to the Life Safety Code. Thus the score calculated from Tables 1 through 3 of the worksheet should be used.

Referring now to the second column of Table 2.5, new non-sprinklered health care facilities with more than 1 story, and performing the same set of calculations one would find that the following score for each safety category results:

Containment safety	14 points
Extinguishment safety	8 points
People movement safety	9 points
General safety	18 points

In this case the first three categories correspond to the values given in the mandatory safety requirements (see Table 6 of the Fire Zone Safety Evaluation Worksheet presented in Exhibit 2.7 of the previous section) for fire zones located above the first floor in a new health care facility. If this exercise were repeated for the third and fourth columns of Table 2.5, it would be possible to derive the mandatory safety requirement values for fire zones located on the first floor and above the first floor in existing health care facilities. Thus three of the four sets of mandatory safety requirement scores (containment safety, extinguishment safety, and people movement safety) can be derived from the four non-sprinklered cases. If one were to perform the same set of calculations for the seven cases where the health care facility was sprinklered (Table 2.6), one would find that the resulting scores for each safety redundancy requirement would exceed those for the same building type if the building were non-sprinklered.

Cost Saving Potential

Now that the basis for calculating the costs associated with each potential retrofit, the value of each Building Safety Feature which corresponds to strict compliance, and the level of safety provided by strict compliance to the Life Safety Code for each safety redundancy requirement and class of occupancy have been established, it is possible to examine the cost saving potential of the equivalency methodology.

The present discussion assumes that it is the total score for each safety category which is of the utmost importance and not the level of any one Building Safety Feature (recall the statement of the redundancy clause in the Life Safety Code). Based on this assumption it is possible to introduce the concept of cost-effective levels of fire safety. For example, the level of fire safety, be it for sprinklered or for non-sprinklered facilities as reflected in the score for each safety category, provides some degree of latitude in changing the level of two or more of the safety features simultaneously (and perhaps reducing total fire safety costs) while holding the total score constant. To illustrate this point, the concept of equal-protection and equal-cost curves will be used.[1] The basic framework used will be that of cost-benefit analysis.[2,3] Cost-benefit analysis, by the systematic study and weighing of available alternatives, provides a guide for increasing the efficiency with which financial and other resources are allocated. Under certain circumstances cost-benefit analysis could be used to identify the optimal level of fire safety.[4] In a more general framework cost-benefit analysis may be used to determine the most efficient level of safety for a given dollar expenditure or conversely the least-cost means of achieving a given level of safety. This implies that the costs which are relevant in determining the most efficient level of protection[5] (general safety, for example) within the framework of cost-benefit analysis are the least-cost means for producing any level of safety.

In order to illustrate this concept and to introduce some of the topics which will be discussed in Section 2.6, it is necessary to make several simplifying assumptions. In particular, it will be assumed that there are only two techniques, A and B (for example, two of the 13 Building Safety Features), which produce general safety. Furthermore, it will be assumed that the levels of these two techniques are continuously variable. (For example, the level of each technique may be the number of minutes

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[1] This treatment bears heavily on some of the previous work conducted by one of the authors. For a comprehensive treatment the interested reader is referred to Robert E. Chapman and Peter F. Colwell, The Economics of Protection Against Progressive Collapse, National Bureau of Standards, NBSIR 74-542, September 1974.

[2] E. J. Mishan, Cost-Benefit Analysis: An Introduction, Praeger, Washington, D.C., 1971.

[3] Cost-benefit analysis is sometimes called risk-benefit analysis in the context of safety.

[4] Any such approach would have to assess all social costs and benefits regardless to whom they accrue. For an in-depth discussion of how this analysis would be conducted the interested reader is referred to John S. McConnaughey, An Economic Analysis of Building Code Impacts: A Suggested Approach, National Bureau of Standards, NBSIR 78-1528, October 1978.

[5] Implicit in this statement is that some minimum level, as identified by the Life Safety Code or the Equivalency Methodology, is attained. The fact that this level may not be economically efficient is best handled by the methodology developed by McConnaughey.

of fire resistance provided by that technique.) This concept may be illustrated graphically. In Figure 2.1 the level, or fire resistance, of each technique is measured along the appropriate axis. The curves in Figure 2.1 which are labeled q_1, q_2, and q_3 are equal-protection curves. Each equal-protection curve indicates all those combinations of techniques A and B which will produce an equal amount of general safety. In Figure 2.1, higher equal-protection curves indicate higher levels of general safety. (In the context of the Fire Zone Safety Evaluation Worksheet, higher equal protection curves imply higher scores.) Suppose the curves q_1, q_2, and q_3 are thought of as being associated with three different fire zone locations. For example, q_1 could correspond to the required level of general safety for a fire zone on the first floor of an existing health care facility. Similarly, q_2 and q_3 could correspond to the required level of general safety for fire zones on the third and sixth floors of the same health care facility. In such a case a particular score could be attached to each equal-protection curve. For example, let q_1 have a score of 4 points, q_2 a score of 7 points, and q_3 a score of 10 points.

The straight lines in Figure 2.1, labeled C_1, C_1^*, C_2, C_3, and C_3^*, are equal-cost lines based on the assumption that the unit prices of techniques A and B are constant. Each equal-cost line shows all the combinations of techniques A and B which cost the same. In Figure 2.1, higher equal cost lines indicate greater costs. Thus the least-cost combination of techniques A and B for producing a certain level of general safety is the one where the lowest possible equal-cost line touches (is tangent to) the specific equal-protection curve in question. Points α, β, and γ are the least-cost combinations which produce q_1, q_2, and q_3 units of general safety. By allowing only one of the two techniques to vary (for example, as a result of strict compliance to a code provision[1]), the resulting combinations of the two techniques are not necessarily least-cost combinations. Thus, if one were to hold technique B constant at level B_1 and just vary the level of technique A, q_1 would be produced at C_1^* which is higher than C_1, q_2 would be produced at C_2, and q_3 would be produced at C_3^* which is higher than C_3.

Figure 2.2 further illustrates this point by showing costs as a function of the level of general safety being produced. The C* function shows the costs of producing various levels of general safety while holding the level of technique B constant. The C function shows the lowest cost (that is, it implies only the most cost-effective methods are used) of producing various levels of general safety. Any cost curve which is not derived from the path of tangency points between the equal-protection curves and the equal-cost lines <u>cannot</u> be below the C function. Therefore, the C function is the lower envelope of all other cost curves

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[1] Refer to Tables 2.5 and 2.6 for an illustration of this point. An examination of these tables reveals that the flame spread rating for interior finishes in rooms is Class B in all eleven cases of strict compliance.

FIGURE 2.1 EQUAL-COST LINES AND EQUAL-PROTECTION CURVES

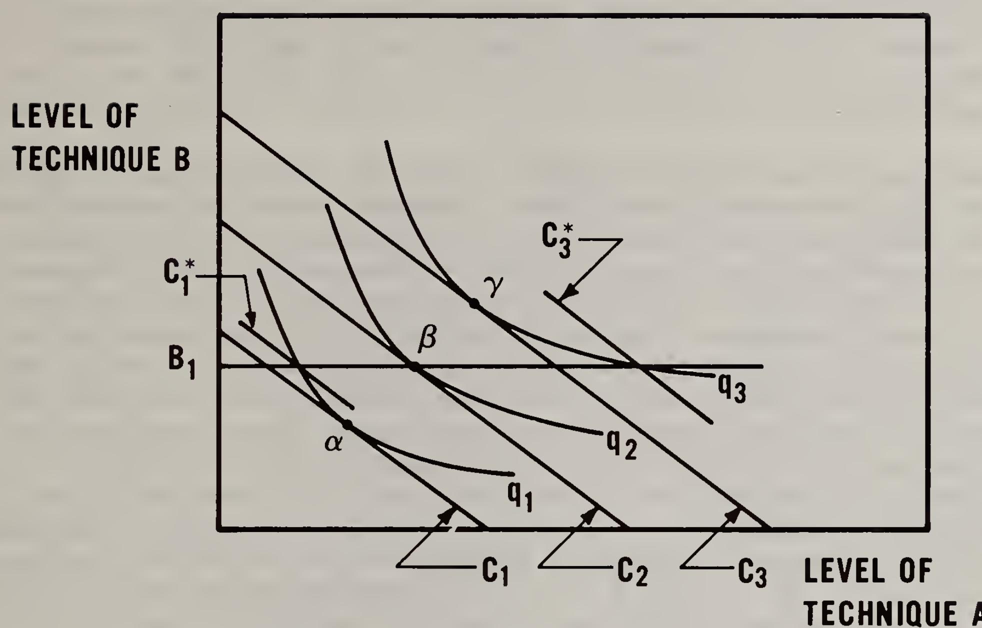
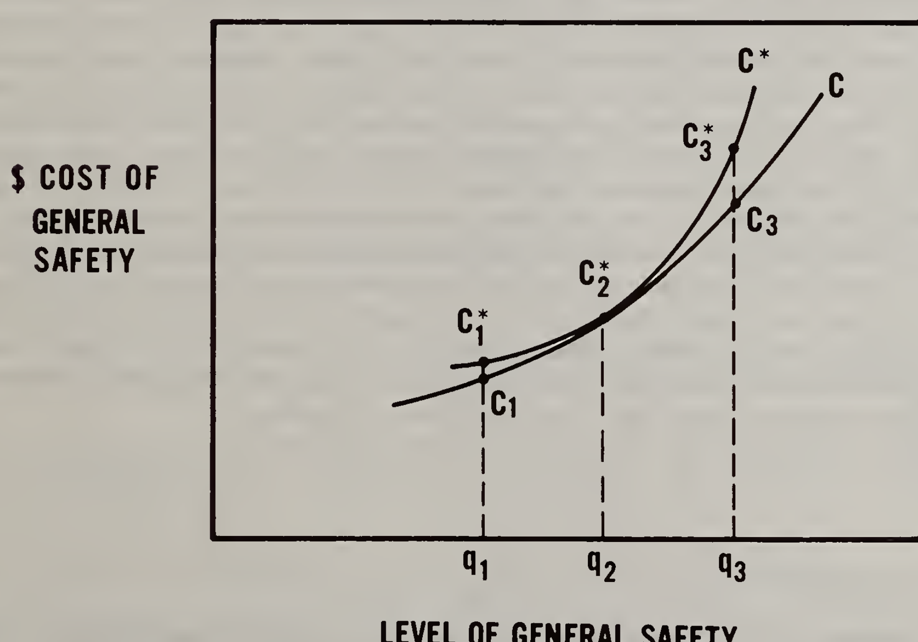


FIGURE 2.2 COSTS AS A FUNCTION OF THE LEVEL OF GENERAL SAFETY BEING PRODUCED



derived from the same equal-cost and equal-protection curves. It is the C function which is relevant for determining the most efficient level of general safety. Note that strict compliance to a fire safety code, as the Life Safety Code, does not guarantee that the solution will be on the C curve. Only with an Equivalency Methodology it is possible to guarantee that the solution will be the most cost-effective and hence lie on the C curve.

Assume that the C* curve corresponds to the cost resulting from adherence to the prescriptive provisions of the Life Safety Code for each of the three fire zone locations examined. The C curve may then be thought of as the costs resulting from providing an equivalent level of general safety through the use of an Equivalency Methodology for each of the three fire zone locations. Potential savings attributable to the use of an Equivalency Methodology may now be read directly from the C and C* curves. In the first case, where it was assumed that the fire zone was located on the first floor of the health care facility, the cost savings are equal to C_1^* minus C_1. In the second case, where it was assumed that the fire zone was located on the third floor of the health care facility, no savings are attributable to the Equivalency Methodology since the same solution is provided through strict compliance to the Life Safety Code. In the third case, where it was assumed that the fire zone was located on the sixth floor, the cost savings are equal to C_3^* minus C_3. Thus the actual savings attributable to the Equivalency Methodology are bounded from below by zero.

In calculating savings attributable to the Equivalency Methodology one must not lose sight of the fact that the solution must satisfy all four safety categories (containment, extinguishment, people movement, and general) simultaneously. Although the approach taken here has focused on only one category, general safety, and only two of the 13 Building Safety Features, the basic methodologies will apply to the four category-13 Building Safety Feature case. (For those readers wishing a "theoretical" discussion of the mathematical underpinnings of the above claim which includes multivariate calculus and constrained optimization, both with single and multiple constraints, the text by Silberberg is highly recommended.[1] The word theoretical has been placed in quotations in the sentence above since each of the 13 Building Safety Features is not continuously variable as was assumed in the previous discussion. It is important to point out that most of the concepts introduced in this section, including unit costs, variations in the scale of the job, and the C and C* functions, can be shown to perform in an analogous manner in the discrete case treated by the computer program.)

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[1] Eugene Silberberg, The Structure of Economics: A Mathematical Analysis, McGraw-Hill Book Company, New York, 1978.

2.5 ADVANTAGES OF THE EQUIVALENCY METHODOLOGY

Past empirical work on fire safety in health care facilities has shown that the use of the Equivalency Methodology could reduce the costs of compliance to the Life Safety Code by 30 to 50 percent.[1] It is important to point out that these reductions are based only on the entries which appear in Table 4 of the Fire Zone Safety Evaluation Worksheet.

Experts in the area of fire engineering claim that through the consideration of addition technical and engineering data these costs can be reduced even further. (Previous studies in other areas have demonstrated the cost saving potential of design innovations.[2]) Thus the Equivalency Methodology not only permits substantial reductions in the costs of compliance to be achieved but also points to areas where additional engineering input would be most cost effective. Although most of the uses of the Equivalency Methodology are geared toward existing buildings several major opportunities exist for its use in the design process. In particular, since its application is simple and straightforward, it is possible to assess numerous design alternatives quickly and efficiently. By the same token, questions concerning the fire zone's configuration, aesthetic qualities, level of fire safety, and costs can also be addressed simultaneously.

Although all of the preceding topics are of crucial importance, perhaps the greatest advantage offered by the Equivalency Methodology is its ability to be adapted to computer optimization techniques. Computer optimization techniques are useful because they identify the least-cost means of achieving compliance to the Life Safety Code. In addition to the least-cost solution, computer optimization techniques provide a systematic procedure for generating from 10 to 20 alternative means of achieving compliance to the Life Safety Code some of which are quite close to the least-cost solution. The added information provided by the alternative solutions will assist health care facility administrators and construction specialists to assess better the costs of code compliance and hence resolve many of the differences of opinion surrounding the cost impacts of fire safety in general and the Life Safety Code in particular. In addition, the information conveyed by the alternative solutions provides an opportunity to introduce the impact that non-construction costs would have on the selection of the "best" retrofit strategy.

2.6 COMPUTERIZED PROCEDURE FOR IDENTIFYING COST-EFFECTIVE RETROFITS

The computerized procedure presented in this section is based on a mathematical technique known as linear programming. In its usual context

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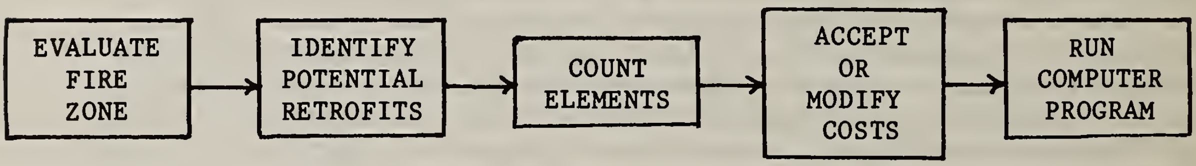
[1] In the context of the last section $(C^* - C)/C^*$ is between 0.7 and 0.5.

[2] Louis J. Krueger and Richard M. Patton, "More Fire Safety Can Cost Less," Hospitals, Vol. 51, February 1, 1977, pp. 127-132.

linear programming deals with the problem of allocating limited resources among competing activities in an optimal way. At the foundation of any linear programming problem is a mathematical model which describes the problem of concern. In this case the mathematical model is the Fire Safety Evaluation System. The term "linear" refers to the requirement that all mathematical functions in the model are linear.[1] The term "program" is used in the general sense in that it refers to a plan rather than a computer program *per se*. The basic reason why all mathematical functions involved in the problem are linear may be explained through reference to Table 4 and Table 5 of the Fire Zone Safety Evaluation Worksheet. In Table 4 there is one and only one level of each factor possible at any one time.[2] This is due to the requirement that the most hazardous level associated with each feature determines the score for that feature. In Table 5 the score for each of the four safety redundancy requirements (containment safety, extinguishment safety, people movement safety, and general safety) is the sum of the values of the appropriate parameter identified in Table 4 as either the existing state or a potential retrofit.

The method of approach taken in developing and using the linear programming procedure has the Fire Safety Evaluation System as its foundation. The steps which must be taken in order to go from the basics of the Fire Safety Evaluation System to the linear programming procedure are shown in Figure 2.3.

Figure 2.3 User Flowchart



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[1] A linear function is defined as a function of the form

$$f(X) = a_o + a_1x_1 + \cdot \cdot \cdot + a_nx_n$$

where a_j are coefficients not all zero and the x_j are variables. The geometrical representation of a linear function is a straight line, a plane,or a hyperplane. For example, $f(x) = a + bx$, a straight line, is a linear function where as $g(x) = c + dx^2$, a parabola, is not.

[2] The above condition requires that all variables corresponding to safety feature levels must be either zero or one. This requirement implies that the problem actually solved is an integer program. The solution to a linear programming problem yields continuous rather than integer variables; however, it can be shown, because of the constraint structure of the model, that the continuous solution is always "nearly" integer.

Figure 2.3 displays the sequence of steps between the Fire Safety Evaluation System and the computerized procedure. As a first step the Fire Zone Safety Evaluation Worksheet must be used to identify the existing state of each of the 13 Building Safety Features. Plugging this information into Table 5 of the worksheet permits the existing state of each feature and the fire zone to be identified. Using the information on the existing state for each feature as a starting point, engineering judgment may then be used to identify a set of potential retrofits.[1] It is important to point out that based on engineering judgment some "theoretically" possible retrofits may be excluded. (A theoretically possible retrofit is any parameter which has a higher score than the parameter corresponding to the existing state.) One important opportunity which should not be overlooked is the collection of information on potential retrofits during the safety inspection. As indicated in the third block, once a set of potential retrofits has been identified it is then necessary to count the number of elements which must be treated in order to move to a higher state. For example, the number of "No Door" charges within the fire zone that would have to be removed in order to ensure that all doors had a fire rating of 20 minutes. The fourth step in the sequence of events relates to the unit cost or cost per element. These costs are the ones actually used in performing the economic analyses. They are an integral part of the procedure and are stored in an "element cost matrix." This cost matrix interacts with the information on the number of elements in the following way. Associated with each potential retrofit is a set of information on the one or more elements which must be treated to move to a higher state (see Table 2.4). This "format" is followed when information on the number of elements is input. All of this information is then stored in an "element count matrix." The product of the element count and element cost matrices yields the total cost associated with each potential retrofit. It is important to point out that the user has the option to accept or modify any information contained in the element cost matrix. The engineering considerations underlying the per unit or per element costs are presented in Chapter 3 and Appendix A. Thus should the user feel that the information in the element cost matrix does not adequately reflect the costs associated with the local construction market or is inappropriate on some other grounds, it can be modified either through the use of time-location factors or changing one or more of the engineering assumptions.

The information identified in the sequence of steps outlined above is the <u>only</u> information required to run the computerized procedure. Although the computerized procedure is only a "working prototype" a maximum amount of flexibility has been built into it.[2] This section

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[1] Engineering input is important at all stages of the procedure but is particularly important in identifying potential retrofits.

[2] In particular, the computerized procedure contains a series of user options which make it possible to alter the cost of any retrofit, preclude a retrofit, force a retrofit to be included, or demand a higher level of safety than required by the Life Safety Code.

has not focused on the mechanics through which the computerized procedure operates and generates solutions. The intent of this section was to provide a general overview rather than stress programming details. For those readers interested in the steps which must be taken in order to use the procedure, a comparison report--A Computerized Approach for Identifying Cost-Effective Fire Safety Retrofits in Health Care Facilities--has been prepared.[1] The companion report consists of program documentation, flow charts, format statements, sample computer runs and a complete listing of the computer program.

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[1] R. E. Chapman, W. G. Hall, and P. T. Chen, A Computerized Approach for Identifying Cost-Effective Fire Safety Retrofits in Health Care Facilities, National Bureau of Standards, NBSIR, (In Press).

Engineering input is of vital importance at all stages of the building process. The Fire Safety Evaluation System is designed to maximize the impact of the engineering expertise at the disposal of health care facility administrators.

3. COST CONSIDERATIONS: A CASE STUDY

The development of the cost considerations presented in this chapter closely parallels the discussion of the Life Safety Code, the Equivalency Methodology and the computerized procedure presented in Chapter 2. These cost considerations play a key role in the process of choosing among alternative retrofit scenarios for a fire zone in a health care facility.

The cost considerations presented in this chapter include:

(1) the selection of a prototypical hospital design suitable for applying the concepts developed in Chapter 2;
(2) the enumeration of all fire zones within the prototypical hospital;
(3) the evaluation of the existing levels of each of the 13 Building Safety Features for each fire zone;

(4) the establishment of fire safety retrofit strategies for each feature based on sound design judgment; and
(5) the preparation of a cost estimate for each retrofit strategy for each Building Safety Feature.

Information on the existing state of each Building Safety Feature, potential retrofits for that feature, counts on the number of elements which must be treated to move to a higher state, and element costs are input into the computer program causing a series of detailed cost analyses to be performed. These analyses include cost comparisons between the least-cost solution and strict compliance solution as well as among the least-cost solution and the set of alternative solutions. The results of the cost comparisons are presented in Section 3.3.

3.1 SELECTION OF A PROTOTYPICAL HOSPITAL

In order to identify the relevant engineering and architectural design information for hospitals that would be suitable for the synthesis of the protypical hospital, it was convenient to work closely with the Central Office of the Veteran's Administration (VA). The VA was selected as the primary information source for several reasons. First, the VA could make available designs on more than 170 hospitals of various ages. Second, the VA has cost information on many of the potential retrofits which are identified in the Fire Safety Evaluation System. Finally, through contact with the National Bureau of Standards, a number of VA personnel have become familiar with the Fire Safety Evaluation System. Based on discussions with the VA personnel and the application of engineering judgment, four hospitals were selected. These designs were selected because they represent the typical designs of the VA's hospitals. The four hospitals selected and their date of construction are summarized in Table 3.1.

Table 3.1 Hospital Layouts Used to Generate Data for the Prototypical Hospital

Hospital Location	Date Built	Number of Typical Buildings (Other VA Hospitals)
Dallas, Texas	1951	15
Jackson, Mississippi	1958	6
Atlanta, Georgia	1962	9
Bronx, New York	1974	8

Using information from the layouts of these hospitals, a prototypical hospital design was then synthesized. The process through which the prototypical design was synthesized involved the reconstruction of a hospital design in which many construction features, although they were perfectly acceptable at the time of their construction, may require modification in order to meet the requirements of the 1973 Life Safety Code. This prototypical design was used in conducting the cost cases presented in Section 3.3. A brief description of the prototypical design is given in the following section.

3.2 The Prototypical Hospital Design

The design of the prototypical hospital presented in this chapter was selected to illustrate the process of: (1) identifying retrofit strategies and alternatives to upgrade the facility to the requirements of the 1973 Life Safety Code; (2) selecting retrofit features which would satisfy strict compliance to the 1973 Life Safety Code; and (3) selecting the least-cost combination of retrofits which complies with the 1973 Life Safety Code.

Figure 3.1 is an isometric view of the prototypical hospital. It reveals a seven story "T" shaped structure. The structure is assumed to be a general hospital housing approximately 300 patients. There is a full basement and a small penthouse provided to house the machinery for the four elevators. The hospital is assumed to have been built around 1960. It is constructed with structural steel framing protected by a fire resistive concrete covering, reinforced concrete floors, fixed windows and masonry exterior walls. Heating, ventilation and air-conditioning is also provided throughout the hospital. The design features of each fire zone are described in the following subsection.

3.2.1 Configuration of the Fire Zones

In all but one case, there is a single fire zone for the basement and each of the seven floors in this hospital. The design features upon which the requirements of the Life Safety Code impinge are therefore listed for each floor. In each case this scenario is based on design experience and engineering judgment and upon assumptions of what an actual inspection of the premises would reveal.

The Basement

The basement floor layout is shown in Figure 3.2. It is neither used by any patients nor in any patient egress route. Mechanical and electrical rooms housing the building service equipment are located on this floor and take up approximately 50 percent of the total floor area. There are also two storage rooms, a cafeteria, a kitchen and other small rooms. The reinforced concrete basement walls and first floor slab together with three enclosed stair exits make this (basement) floor fire resistive. A complete extinguishment system is provided for the entire floor. The Fire Safety Evaluation System will not be applied to this floor since it is

Figure 3.1

ISOMETRIC VIEW OF THE PROTOTYPICAL HOSPITAL

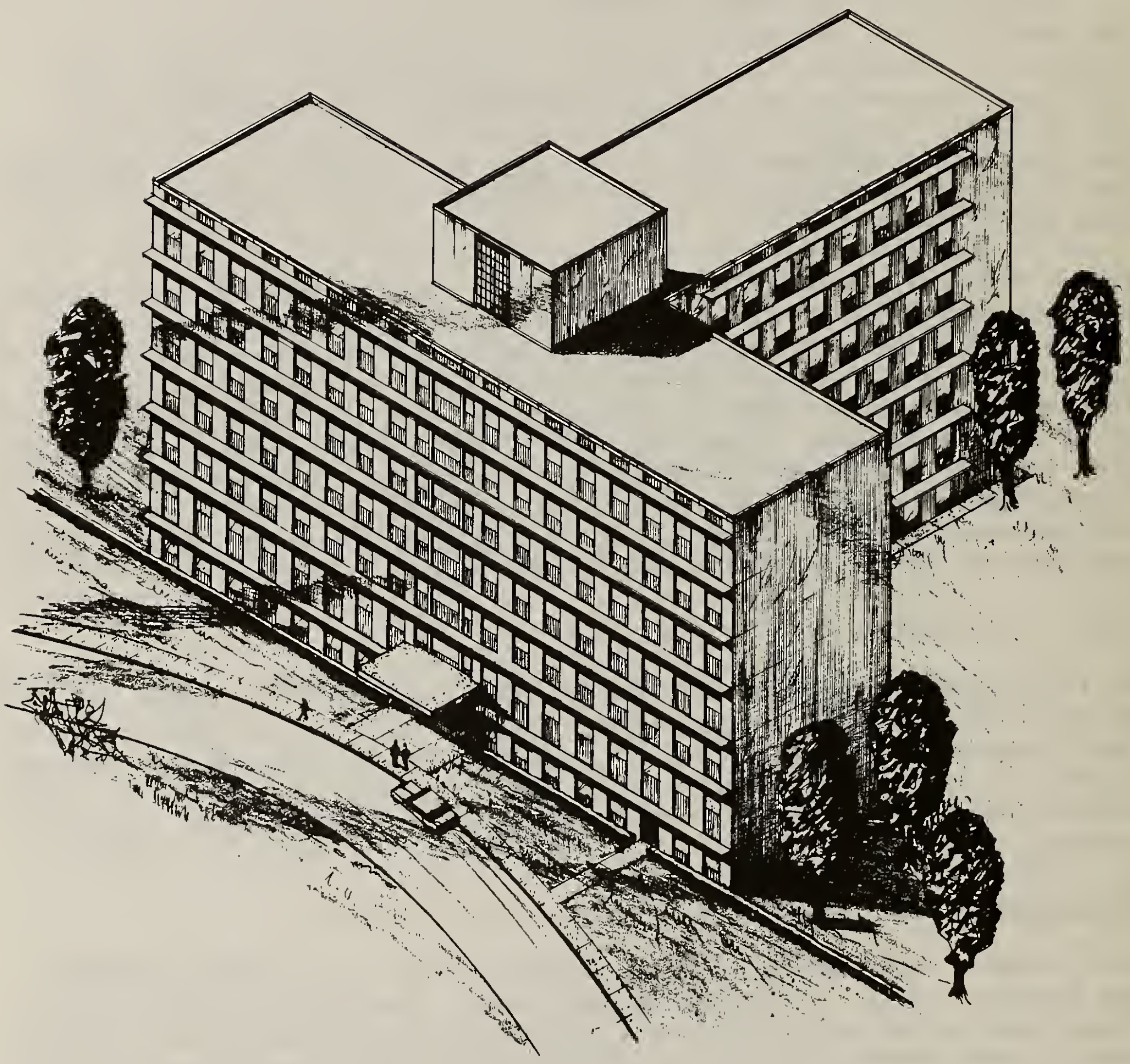
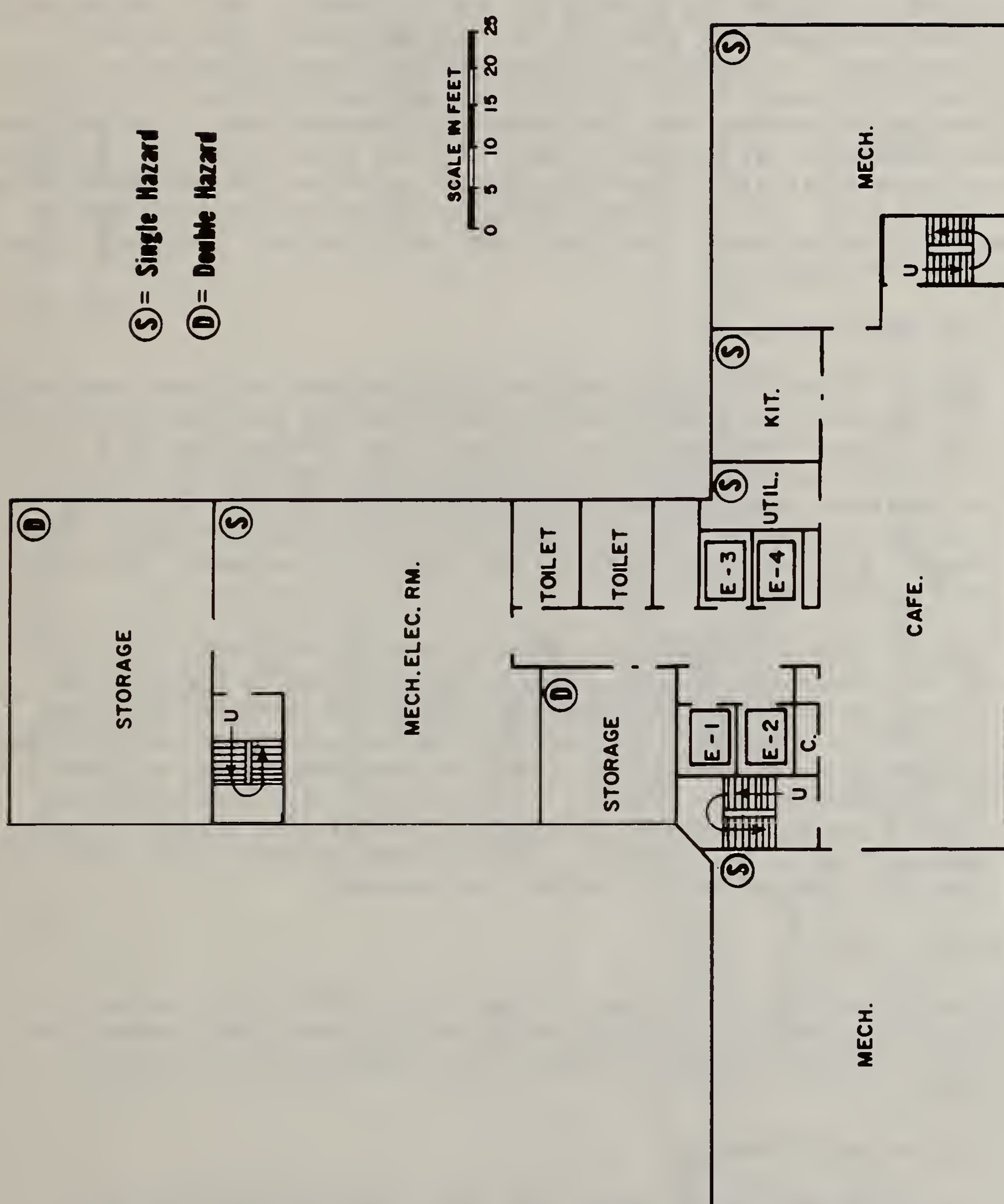


Figure 3.2

FLOOR PLAN OF THE PROTOTYPICAL HOSPITAL: BASEMENT FLOOR



not used by any patients and since a fire resistive enclosure with an automatic extinguishment system is between it and patient areas.

The First Floor

The first floor layout is shown in Figure 3.3. This floor is divided into two fire zones denoted as Zone 1 and Zone 2 in Figure 3.3. Emergency treatment rooms are located in Zone 1. The out patient clinic, pharmacy, auditorium and offices are located in Zone 2. Zones 1 and 2 are separated by a horizontal exit with a fire door. The horizontal exit dividing Zone 2 and Zone 1 is designated by the darkened line in Figure 3.3. From the basement and upper floors there is one enclosed stairway which exits into the Zone 2 corridor near the emergency treatment area. Two additional enclosed stairways may be used to exit into the Zone 2 corridor. However, both of these exits also have direct access to the outside of the building (see Figure 3.3). Zone 2 is thus listed as being on a patient egress route. Three other exits from Zone 2 and one other exit from Zone 1 are also shown in Figure 3.3.

Fire Hazard Scenario:

Zone 1: There is enough space for five patients and four attendants. The interior finish as Class A is evaluated for the corridor and exits and as Class B for the rooms. Doors to the corridor are of a fire rating of less than 20 minutes; there are no dead-end corridors and no hazardous areas. There is one horizontal exit which may also be claimed as a smoke partition, and there is a localized manual fire alarm. Neither smoke detectors and alarms nor automatic extinguishment devices are provided.

Zone 2: There are generally about 10 outpatients being cared for by one attendant. Interior finish for the rooms is evaluated as Class C; corridor partition walls are rated at between 20 minutes and one hour; doors to the corridor have a fire rating of less than 20 minutes. The two utility rooms and the pharmacy are evaluted as hazardous areas. There is one horizontal exit located between Zones 1 and 2, and there are localized manual fire alarms in three places. Again, as in Zone 1, neither smoke detectors and alarms nor automatic extinguishment devices are provided.

The Second Floor

The second floor layout is shown in Figure 3.4. This floor contains surgery and recovery areas, x-ray areas, utility and storage areas, and some office spaces. There are three exits leading into the enclosed stairways.

Fire Hazard Scenario:

The entire floor is a single fire zone. Ten patients and six attendants are assumed to occupy the floor at any one time. In

Figure 3.3

FLOOR PLAN OF THE PROTOTYPICAL HOSPITAL: FIRST FLOOR

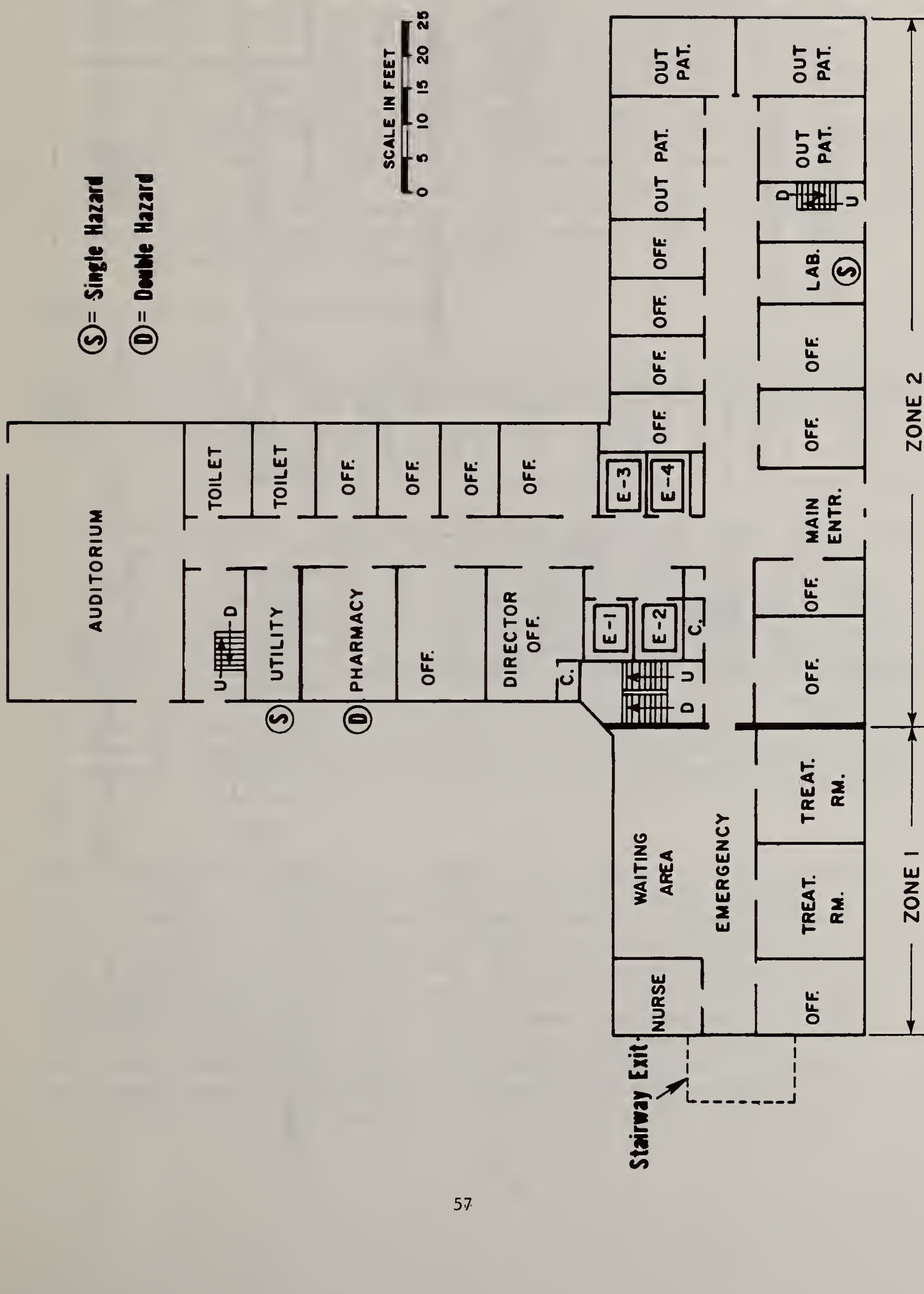
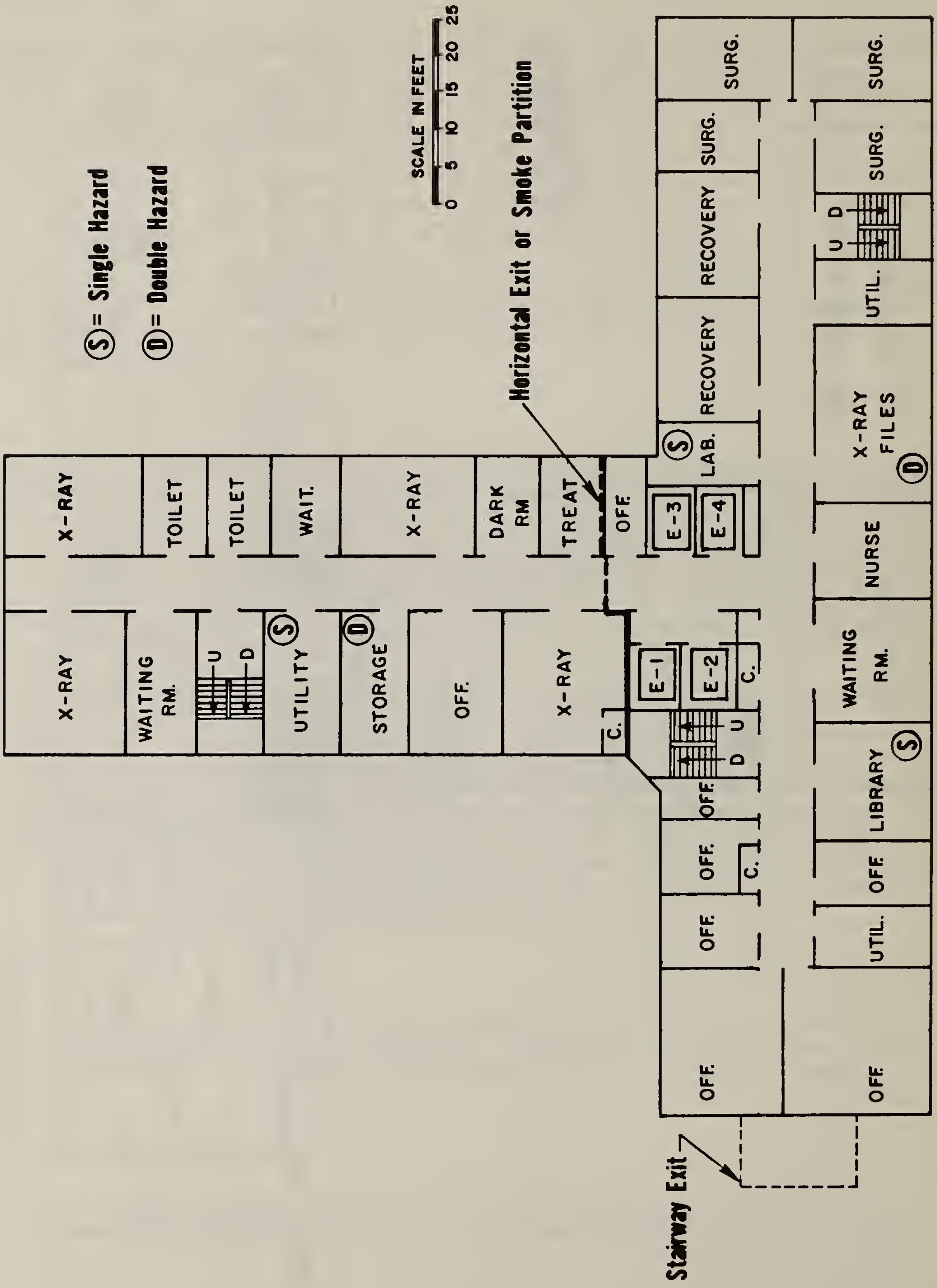


Figure 3.4

FLOOR PLAN OF THE PROTOTYPICAL HOSPITAL: SECOND FLOOR



addition to the patients and attendants, a maximum of 20 office workers and medical technicians may occupy the floor. All construction is of the noncombustible, fire-resistive type, and some interior finishes in the corridors, exits and rooms have Class C flame spread ratings. All corridor partition walls are rated at between 20 minutes and one hour; doors to the corridor have less than a 20 minute fire rating; all dead-end corridors are less than 30 feet in length with the longer corridor being 135 feet in length. Doors and door frames for the three exis are rated at less than one hour of fire resistance. There is no automatic extinguishment system in any of the hazardous areas[1] (e.g., library, x-ray file room, storage room and laboratory). There is no provision for smoke control, and there are three emergency movement routes without any horizontal exits. There are two localized manual fire alarm stations, and there are neither smoke detectors and alarms not automatic extinguishment devices.

The Third Through Seventh Floors

The third through seventh floor layouts are shown on Figure 3.5. Each of these floors provides sleeping facilities for patients, a kitchen, rooms for clean and soiled linen and other areas as shown on the figure. Each floor is a single fire zone.

Fire Hazard Scenario:

The maximum number of patients is 58 per floor, and there are 5 attendants for each floor. Construction of all floors is of the noncombustible--fire resistive type; and some interior finishes in the corridors, exits and rooms have a Class C flame spread rating. There are three large wired glass openings enclosed with non-UL approved frames. All interior doors have less than a 20 minute fire rating with ordinary glass lights, and a few have defective latches. The longest dead-end corridor is 45 feet in length within a 135 foot long corridor. Doors and door frames for the three exits are rated at less than one hour of fire resistance; and there is no extinguishment system in the hazardous areas (laboratory, kitchen, linen rooms and storage room).

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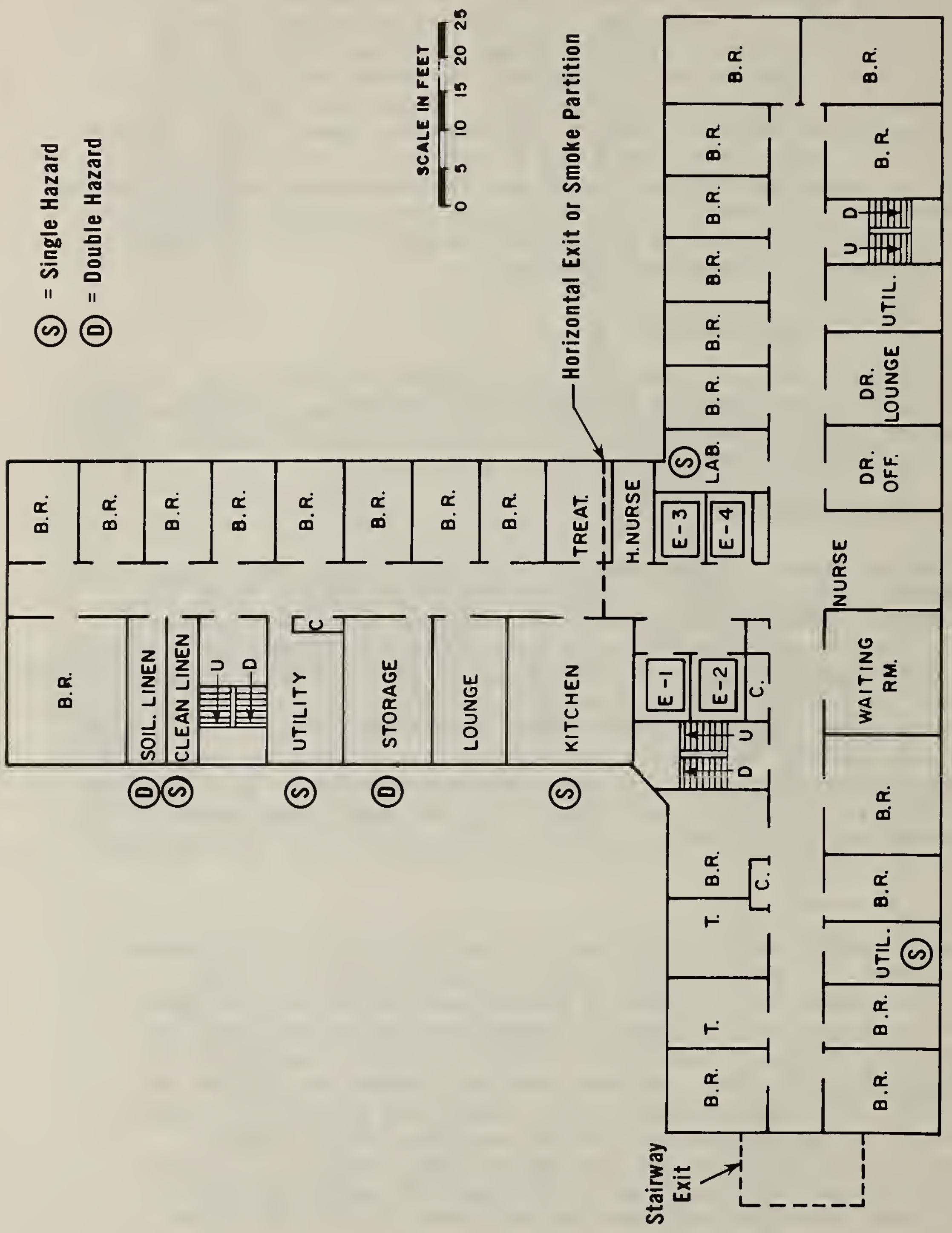
[1] High hazard areas (double deficiency) identified by the Life Safety Code include: 1) soiled linen rooms; 2) paint shops; 3) trash collection rooms; and 4) rooms or spaces used for storage of combustible supplies and equipment in quantities deemed hazardous by the authority having jurisdiction. (The fire hazard potential of pharmacies, laboratories, and other medical support activities can vary widely from nonhazardous to high hazard and thus must be evaluated on a case by case basis.) Other hazardous areas (single deficiency) identified by the Life Safety Code include: 1) boiler and heater rooms; 2) laundries; 3) kitchens; 4) repair shops; 5) handicraft shops; 6) employee locker rooms; and 7) gift shops.

FIGURE 3.5 FLOOR PLAN OF THE PROTOTYPICAL HOSPITAL: THIRD THROUGH SEVENTH FLOORS



There is no provision for smoke control, and there are three emergency movement routes without any horizontal exits. There are two localized manual fire alarm stations, and there are neither smoke detectors and alarms nor automatic extinguishment devices.

3.2.2 The Retrofit Scenario

Before a complete retrofit scenario can be formulated, several engineering issues relating to the assessment and evaluation of the existing prototypical hospital must be addressed. Table 3.2 serves as a summary and overview of the occupancy risk factors for each fire zone.

Identifying Retrofits

Tables 3.3 through 3.6 list the engineering assessment of the existing conditions of the design features for each fire zone used to define the initial state of each of the 13 Building Safety Features listed in Table 4 of the Worksheet. Table 3.7 summarizes element counts and several other critical factors that will be used in the cost comparisons. In particular, these quantities will be used to develop cost estimates for the alternative retrofits discussed in Section 3.3. The potential retrofits associated with each factor in each fire zone are summarized in Tables 3.8 through 3.10.

Pricing Retrofits

The estimated cost of each potential retrofit is presented in Tables 3.11 through 3.14. These prices were obtained by combining the information presented in Tables 3.8 through 3.10 with the per unit or per element costs presented in Appendix A. In practice the pricing information presented here would only be the first cut at a final overall estimate of the cost of the retrofit package. For this reason detailed construction specifications will not be given. Construction specifications would, however be written prior to the preparation of a final construction estimate. (It is important to point out that the user could easily check whether or not the retrofit package upon which the final estimate is based is appropriate through the use of the CHANGE option described in the companion report.)

Table 3.2 Summary of Occupancy Risk Factors in Each Fire Zone

Fire Zone	Patient Mobility (M)[a]	Patient Density (D)	Zone Location (L)	Ratio of Patients to Attendant (T)	Patient Average Age (A)
Basement	N.A	N.A.	N.A	N.A.	N.A.
1st Floor Zone 1	3.2	1.0	1.1	1.0	1.2
1st Floor Zone 2	1.0	1.2	1.1	1.5	1.2
2nd Floor Single Zone	3.2	1.2	1.2	1.0	1.2
3rd Floor Single Zone	3.2	2.0	1.2	1.2	1.2
4th Floor Single Zone	1.6	2.0	1.4	1.2	1.2
5th Floor Single Zone	1.6	2.0	1.4	1.5	1.0
6th Floor Single Zone	1.6	2.0	1.4	1.5	1.0
7th Floor Single Zone	1.6	2.0	1.6	1.5	1.0

Legend
N.A. = not applicable

[a] Letters denote entries in Table 2 of the Fire Zone Safety Evaluation Worksheet.

Table 3.3 Existing Condition of Each Building Safety Feature in Zone 1 of the First Floor

Building Safety Feature	Description	Value
1. Construction	Non-combustible/ fire resistive	2
2. Interior Finish (Corridor and Exit)	Class A Finish	3
3. Interior Finish (Rooms)	Class B Finish	1
4. Corridor Partition Walls	Between a 20 minute and 1 hour fire rating	1
5. Doors to Corridor	Less than a 20 minute fire rating	0
6. Zone Dimensions	No dead ends	1
7. Vertical Openings	Between a 1 and 2 hour fire rating	2
8. Hazardous Areas	None	0
9. Smoke Control	Smoke Partition	0
10. Emergency Movement Routes	Multiple routes with a horizontal exit	3
11. Manual Fire Alarm	Manual fire alarm without fire department connection	1
12. Smoke Detection & Alarm	None	0
13. Sprinklers	None	0

Table 3.4 Existing Condition of Each Building Safety Feature in Zone 2 of the First Floor

Building Safety Feature	Description	Value
1. Construction	Non-combustible/ fire resistive	2
2. Interior Finish (Corridor & Exit)	All corridor ceiling is of Class C (accoustical ceiling)	-5
3. Interior Finish (Rooms)	Class C plywood panel in the Medical director's office	-3
4. Corridor Partition Walls	Between a 20 minute and 1 hour fire rating	2
5. Doors to Corridor	Less than 20 minutes of fire resistance with some defective latches	0
6. Corridor Length	All dead ends are less than 30 feet in length	0
7. Vertical Opening	3 exit doors and frames to stairways are of less than 1 hour of fire resistance	0
8. Hazardous Areas	The pharmacy and other hazardous areas do not have an extinguishment system	-11
9. Smoke Control	Smoke Partition	0
10. Emergency Movement Routes	Multiple routes with horizontal exits	3
11. Manual Fire Alarm	Manual fire alarm without fire department connection	1
12. Smoke Detection & Alarm	None	0
13. Sprinklers	None	0

Table 3.5 Existing Condition of Each Building Safety Feature on the Second Floor

Building Safety Feature		Description	Value
1.	Construction	Non-combustible/ fire resistive	4
2.	Interior Finish (Corridor & Exit)	All corridor ceiling is of Class C (acoustical ceiling)	-5
3.	Interior Finish (Rooms)	Class C plywood paneling in the waiting rooms and in the library	-3
4.	Corridor Partition Walls	1/3 to 1 hour fire rating	1
5.	Doors to Corridor	Less than 20 minutes of fire resistance with some defective latches	0
6.	Zone Dimensions	All dead ends are less than 30 feet in length	0
7.	Vertical Opening	3 exit doors and frames to stairways have less than 1 hour of fire resistance	0
8.	Hazardous Areas	No extinguishment system in the x-ray file room, library, storage room and other hazardous areas	-11
9.	Smoke Control	None	0
10.	Emergency Movement Routes	Multiple routes without horizontal exits	0
11.	Manual Fire Alarm	Manual fire alarm without fire department connection	1
12.	Smoke Detection & Alarm	None	0
13.	Sprinklers	None	0

Table 3.6 Existing Condition of Each Building Safety Feature on the Third Through Seventh Floors

Factor		Description	Value
1.	Construction	Non-combustible/ fire resistive	4
2.	Interior Finish (Corridor & Exit)	All corridor ceiling is of Class C (acoustical ceiling)	-5
3.	Interior Finish (Rooms)	Class C plywood paneling in Doctor's offices, Doctors' lounge and the waiting room	-3
4.	Corridor Partition Walls	3 wired glass openings (1000 square inches each) do not have approved steel frames	0
5.	Doors to Corridor	Doors have less than 20 minutes of fire resistance, doors have ordinary glass lights (700 square inches each) and a defective latch	-10
6.	Zone Dimensions	45 foot dead end in one corridor	-4
7.	Vertical Openings	3 exit doors and frames to stairways have less than 1 hour of fire resistance	0
8.	Hazardous Areas	No extinguishment system in any hazardous areas	-11
9.	Smoke Control	None	-2
10.	Emergency Movement Routes	Multiple routes without horizontal exits	0
11.	Manual Fire Alarm	Manual fire alarm without fire department connection	1
12.	Smoke Detection & Alarm	None	0
13.	Sprinklers	None	0

Table 3.7 Summary of Element Counts[a]

Floor and/or Fire Zone	Number of of Doors[b]	Number of Elevator Doors	Number of Exit Doors	Number of Doors to Hazardous Areas	Corridor Length (Feet)	Corridor Dead Ends (Feet)	Corridor Area (Square Feet)	Hazardous Areas (Square Feet)	Fire Zone Area (Square Feet)
Basement	4	4	3	8	40	N.A.	320	6360	8700
Floor 1 Zone 1	4	0	2	0	0	0	0	0	1700
Floor 1 Zone 2	23	4	5	3	77 93	17	1400	600	7000
Floor 2	31	4	3	5	105 115	17 25 25	2000	960	8700
Floor 3	35	4	3	7	105 135	17 25 45	2000	1090	8700
Floor 4	35	4	3	7	105 135	17 25 45	2000	1090	8700
Floor 5	35	4	3	7	105 135	17 25 45	2000	1090	8700
Floor 6	35	4	3	7	105 135	17 25 45	2000	1090	8700
Floor 7	35	4	3	7	105 135	17 25 45	2000	1090	8700

[a]Element counts reflect the total number of each element in the existing zone. These quantities are independent of the state of any of the 13 Building Safety Features. Critical element counts, those elements which must be treated to move to a higher state, are given in Table 3.11.

[b]This figure does not include elevator doors, exit doors, and doors on hazardous areas.

Table 3.8 Potential Retrofits for Zone 2 of the First Floor

Building Safety Feature	State 1	State 2	State 3	State 4	State 5
1. Construction	-	-	0	-	-
2. Interior Finish (Corridor and Exit)	0	Paint acoustical ceiling to achieve a Class B flame spread rating.	Paint acoustical ceiling to achieve a Class A flame spread rating.	-	-
3. Interior Finish (Rooms)	0	Treat plywood paneling to achieve a Class B flame spread rating.	Treat plywood paneling to achieve a Class A flame spread rating.	-	-
4. Corridor Partition Walls	-	-	0	-	-
5. Doors to Corridor	-	0	Replace doors as necessary to achieve a greater than 20 minute fire rating.	Replace doors as necessary to achieve a greater than 20 minute fire rating. Install automatic closers on all doors.	
6. Zone Dimensions	-	-	-	0	-
7. Vertical Openings	-	-	0	Replace exit fire doors to achieve a fire rating between 1 and 2 hours.	Replace exit fire doors to achieve a fire rating in excess of 2 hours.
8. Hazardous Areas	0	-	Install sprinklers in all high hazard areas.	-	Install sprinklers in all hazardous areas. Install Class A fire doors in high hazard areas.
9. Smoke Control	-	0	-	-	-
10. Emergency Movement Routes	-	-	-	0	-
11. Manual Fire Alarm	-	0	Connect fire alarm to fire department.	-	-
12. Automatic Detection and Alarm	0	Install detectors and alarm in the corridor.	Install detectors and alarm in all rooms.	Install detectors and alarm in all corridors and habitable spaces.	Install detectors and alarm so as to cover all spaces.
13. Sprinklers	0	Install sprinklers in the corridor.	Install sprinklers in all corridors and habitable spaces.	Install sprinklers so as to cover all spaces.	-

Table 3.9 Potential Retrofits for the Second Floor

Building Safety Feature	State 1	State 2	State 3	State 4	State 5
1. Construction	-	-	0	-	-
2. Interior Finish (Corridor and Exit)	0	Paint acoustical ceiling to achieve a Class B flame spread rating.	Paint acoustical ceiling to achieve a Class A flame spread rating.	-	-
3. Interior Finish (Rooms)	0	Treat plywood paneling to achieve a Class B flame spread rating.	Treat plywood paneling to achieve a Class A flame spread rating.	-	-
4. Corridor Partition Walls	-	-	0	-	-
5. Doors to Corridor	-	0	Replace doors as necessary to achieve a greater than 20 minute fire rating.	Replace doors as necessary to achieve a greater than 20 minute fire rating. Install automatic closers on all doors.	-
6. Zone Dimensions	-	-	-	0	-
7. Vertical Openings	-	-	0	Replace exit fire doors to achieve a fire rating between 1 and 2 hours.	Replace exit fire doors to achieve a fire rating in excess of 2 hours.
8. Hazardous Areas	0	-	Install sprinklers in all high hazard areas.	-	Install sprinklers in all hazardous areas. Install Class A fire doors in high hazard areas.
9. Smoke Control	0	Install a smoke partition.	-	-	
10. Emergency Movement Routes	-	-	0	Install a horizontal exit.	-
11. Manual Fire Alarm	-	0	Connect fire alarm to fire department.	-	-
12. Automatic Detection and Alarm	0	Install detectors and alarm in the corridor.	Install detectors and alarm in all rooms.	Install detectors and alarm in all corridors and habitable spaces.	Install detectors and alarm so as to cover all spaces.
13. Sprinklers	0	Install sprinklers in the corridor.	Install sprinklers in all the corridors and habitable spaces.	Install sprinklers so as to cover all spaces.	-

Legend
- Impossible or Infeasible Retrofit
0 Existing State

Table 3.10 Potential Retrofits for the Third Through Seventh Floors

Building Safety Feature	State 1	State 2	State 3	State 4	State 5
1. Construction	-	-	0	-	-
2. Interior Finish (Corridor and Exits)	0	Paint acoustical ceiling to achieve a Class B flame spread rating.	Paint acoustical ceiling to achieve a Class A flame spread rating.	-	-
3. Interior Finish (Rooms)	0	Treat plywood paneling to achieve a Class B flame spread rating.	Treat plywood paneling to achieve a Class A flame spread rating.	-	-
4. Corridor Partition	-	0	Replace see through window frames with approved steel frames to achieve a fire rating of between 20 minutes and 1 hour.	-	-
5. Doors to Corridor	0	Replace ordinary glass lights with wire glass. Replace defective latches.	Replace doors as necessary to achieve a greater than 20 minute fire rating.	Replace doors as necessary to achieve a greater than 20 minute fire rating. Install automatic Closers on all doors.	-
6. Zone Dimensions	-	0	-	Install stairwell to remove dead end.	-
7. Vertical Openings	-	-	0	Replace exit fire doors to achieve a fire rating between 1 and 2 hours.	Replace exit fire doors to achieve a fire rating in excess of 2 hours.
8. Hazardous Areas	0	-	Install sprinklers in all high hazard areas.	-	Install sprinklers in all hazardous areas. Install Class A fire doors in high hazard areas.
9. Smoke Control	0	Install a smoke partition.	-	0	Install a smoke partition.
10. Emergency Movement Routes	-	-	-	Install a horizontal exit.	-
11. Manual Fire Alarm	-	0	Connect-fire alarm to fire department.	-	-
12. Automatic Detection and Alarm	0	Install detectors and slarm in the corridor.	Install detectors and alarm in all rooms.	Install detectors and alarm in all corridors and habitable spaces.	Install detectors and alarm so as to cover all spsces.
13. Sprinklers	0	Install sprinklers in the corridor.	Install sprinklers in all corridors and habitable spaces.	Install sprinklers so as to cover all spaces.	-

Legend
- \- Impossible or Infeasible Retrofit
- 0 Existing State

Table 3.11 Summary of Critical Element Counts[a]

Floor and/or Fire Zone	Interior Finish (Square Feet)	Openings in Corridor Partition Walls	Doors to Corridor[b]	Corridor Lengths (Feet)	Vertical Openings	Hazardous Areas Single Deficiency (Square Feet)	Hazardous Areas Double Deficiency (Square Feet)	Doors (Number)	Smoke Partition	Horizontal Exits[c]	Manual Fire Alarm Stations	Automatic Detection and Alarm[d] (Square Feet)	Sprinklers[e] (Square Feet)
Basement	N.A. (not applicable)	N.A	N.A	N.A	N.A	N.A	N.A	N.A.	N.A	N.A	N.A.	N.A.	N.A.
Floor 1 Zone 1	0	0	0	0	0	0	0	0	1	1	1	0 1700 1700 1700	0 1700 1700
Floor 1 Zone 2	1500 Ceiling 600 Wall	0	19	17' Dead End 93' Corridor	3 Exits	360	240	1	1	1	3	1400 5000 6400 7000	1400 6400 7000
Floor 2	2000 Ceiling 1200 Wall	0	27	25' Dead End 115' Corridor	3 Exits	500	460	2	0	0 25	3	2000 5740 7740 8700	2000 7740 8700
Floor 3	2000 Ceiling 1200 Wall	3 Windows	30	45' Dead End 135' Corridor	3 Exits	770	320	2	0	0 25	3	2000 5610 7610 8700	2000 7610 8700
Floor 4	2000 Ceiling 1200 Wall	3 Windows	30	45' Dead End 135' Corridor	3 Exits	770	320	2	0	0 25	3	2000 5610 7610 8700	2000 7610 8700
Floor 5	2000 Ceiling 1200 Wall	3 Windows	30	45' Dead End 135' Corridor	3 Exits	770	320	2	0	0 25	3	2000 5610 7610 8700	2000 7610 8700
Floor 6	2000 Ceiling 1200 Wall	3 Windows	30	45' Dead End 135' Corridor	3 Exits	770	320	2	0	0 25	3	2000 5610 7610 8700	2000 7610 8700
Floor 7	2000 Ceiling 1200 Wall	3 Windows	30	45' Dead End 135' Corridor	3 Exits	770	320	2	0	0 25	3	2000 5610 7610 8700	2000 7610 8700

[a] Critical element counts reflect the total number of each element in the existing zone which must be treated in order to move to a higher state.

[b] This figure does not include elevator doors, exit doors, and doors on hazardous areas.

[c] The first figure denotes the number of horizontal exits in place. The second figure denotes the linear feet of partition extension from the existing partition to the structural slab required per horizontal exit installed.

[d] From top to bottom the figures represent areas in square feet for corridors, rooms, corridors and habitable spaces and the total space.

[e] From top to bottom the figures represent areas in square feet for corridors, corridors and habitable spaces, and the total space.

Table 3.12 Retrofit Prices for Zone 2 of the First Floor

	Building Safety Feature	State				
		1	2	3	4	5
1.	Construction	-	-	0	-	-
2.	Interior Finish (Corridor and Exit)	0	600	600	-	-
3.	Interior Finish (Rooms)	0	300	300	-	-
4.	Corridor Partition Walls	-	-	0	-	-
5.	Doors to Corridor	-	0	5700	6840	-
6.	Zone Dimension	-	-	-	0,(15000)[a]	-
7.	Vertical Openings	-	-	0	3750	3900
8.	Hazardous Areas	0	-	540	-	3850
9.	Smoke Control	-	0	-	-	-
10.	Emergency Movement Routes	-	-	-	0	-
11.	Manual Fire Alarm	-	0	1000	-	-
12.	Automatic Detection and Alarm	0	3150	11250	14400	15750
13.	Sprinklers	0	2800	12800	14150	-

Legend
- Impossible or Infeasible Retrofit
0 Existing State

[a] The $15000 charge is due to the strict compliance requirement for an exit stairway leading down from the second floor.

Table 3.13 Retrofit Prices for the Second Floor

Building Safety Feature	State				
	1	2	3	4	5
1. Construction	-	-	0	-	-
2. Interior Finish (Corridor and Exit)	0	800	800	-	-
3. Interior Finish (Rooms)	0	600	600	-	-
4. Corridor Partition Walls	-	-	0	-	-
5. Doors to Corridor	-	0	8100	9720	-
6. Zone Dimensions	-	-	-	0,(15000)[a]	-
7. Vertical Openings	-	-	0	3750	3900
8. Hazardous Areas	0	-	1035	-	6860
9. Smoke Control	0	1400	-	-	-
10. Emergency Movement Routes	-	-	0	4650	-
11. Manual Fire Alarm	-	0	1000	-	-
12. Automatic Detection and Alarm	0	4500	12915	17415	19575
13. Sprinklers	0	4000	15480	17640	-

Legend
- Impossible or Infeasible Retrofit
0 Existing State

[a] The $15000 charge is due to the strict compliance requirement for an exit stairway leading down from the third floor.

Table 3.14 Retrofit Prices for the Third Through Seventh Floors

Building Safety Feature	State				
	1	2	3	4	5
1. Construction	-	-	0	-	-
2. Interior Finish (Corridor and Exit)	0	800	800	-	-
3. Interior Finish (Rooms)	0	600	600	-	-
4. Corridor Partition Walls	-	0	1200	-	-
5. Doors to Corridor	0	3000	9000	10800	-
6. Zone Dimensions	-	0	-	15000	-
7. Vertical Openings	-	-	0	3750	3900
8. Hazardous Areas	0	-	720	-	7453
9. Smoke Control	0	1400	-	-	-
10. Emergency Movement Routes	-	-	0	4650	-
11. Manual Fire Alarm	-	0	1000	-	-
12. Automatic Detection and Alarm	0	4500	12623	17123	19575
13. Sprinklers	0	4000	15220	17673	-

Legend
- Impossible or Infeasible Retrofit
0 Existing State

3.3 APPLICATION OF THE COMPUTERIZED PROCEDURE TO A PROTOTYPICAL HOSPITAL

The focus of this section is on the presentation of the results of a series of computer studies based on the prototypical hospital design. The results of the computer studies for each fire zone of the prototypical hospital are presented in Section 3.3.1. In that section a series of retrofit packages are identified for each fire zone. These retrofit packages include not only the least-cost solution and the prescriptive solution, but alternative retrofit strategies as well, such as total sprinklering or the removal of a dead-end corridor. The full range of admissible retrofits[1] generated by the computerized procedure is presented in Section 3.3.1. This approach is intended to stress the flexibility of the Equivalency Methodology. In practice health care facility decision makers would probably wish to consider a subset of the admissible retrofits identified by the computer program in choosing a retrofit strategy for the entire building. Section 3.3.2 addresses this requirement. The approach taken in Section 3.3.2 stresses similarity of retrofits across fire zones. It is felt that this approach is most consistent with the requirement for sound design judgment in the choice of a comprehensive retrofit strategy. This approach also serves to reduce the number of admissible retrofits to a more manageable number. Results from the admissible retrofits considered in Section 3.3.2 support the claim that the Equivalency Methodology can reduce the costs of compliance to the Life Safety Code by 50 percent or more. Furthermore, the use of the Equivalency Methodology permits code compliance to be achieved at a significant reduction in retrofit costs (25 to 35 percent) even if high cost options such as the installation of a stairwell or total sprinklering are included in the retrofit strategy.

3.3.1 Alternative Retrofit Strategies by Fire Zone

The focus of this section is on establishing the technical underpinnings for the results and for the cost saving implications of the use of the Fire Safety Evaluation System Equivalency Methodology presented in Section 3.3.2. Details are given on each of the three fire zones[2] contained in the protypical hospital. A synthesis of the results of this section into

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[1] An admissible retrofit strategy is one which matches or exceeds all four safety redundancy requirements. All admissible retrofit strategies therefore satisfy the Life Safety Code. An admissible retrofit strategy differs from a potential retrofit strategy in that a potential retrofit strategy may not satisfy the four safety redundancy requirements of the Life Safety Code.

[2] Zone 1 of the first floor already satisfies the prescriptive requirements of the Life Safety Code. The third fire zone, the patient room floors, floors three through seven, is repeated five times. See Table 2.5 for a summary of the levels of each factor which corresponds to strict compliance to the Life Safety Code for non-sprinklered facilities.

a comprehensive retrofit strategy is given in Section 3.3.2. Two types of summary information are presented for each fire zone. The retrofits identified by the computerized procedure are first ranked from least costly to most costly and plotted graphically. These results are shown in Figures 3.6, 3.7, and 3.8. Details of each retrofit package are then summarized in Tables 3.16, 3.17, and 3.18. A fourth table, Table 3.15, is included in order to establish a base for comparison. Table 3.15 identifies the initial states for each of the 13 Building Safety Features in the three fire zones under consideration.

First Floor, Fire Zone 2

The initial state for each of the 13 Building Safety Features in Zone 2 of the first floor is shown in the first column of Table 3.15. If the scores associated with the initial state of each of the 13 safety factors were entered onto Table 5 of the Fire Zone Safety Evaluation Worksheet, the result would indicate that in order to achieve compliance to the Life Safety Code the following net improvements would be needed: 19 points in containment safety, 11 points in extinguishment safety, 3 points in people movement safety, and 13 points in general safety.

In order to use the computerized procedure to solve for a cost-effective retrofit strategy for this fire zone, it was necessary to obtain a set of critical element counts. These counts were taken from the floorplans and are summarized in Table 3.11 of the previous section. Through the use of the computerized procedure, seven admissible retrofit strategies were found which had costs less than or equal to the costs of strict compliance. An eighth admissible retrofit strategy corresponding to total sprinklering was also found but was more expensive than the prescriptive (strict compliance) solution.[1,2] A graphical summary of the eight admissible retrofit strategies, ranked from least costly to most costly, is shown in Figure 3.6. A ninth (admissible) strategy, the prescriptive solution, is plotted at the far right. In each case the height of the bar denotes the expected retrofit cost for each strategy. These strategies are identified by a letter along the horizontal axis of the figure which corresponds with a definition of a retrofit package given in Table 3.16. Analysis of Figure 3.6 reveals that retrofit

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1 Several other admissible retrofits which were more expensive than the prescriptive solution were also found. In the other fire zones a certain number of admissible solutions which were more expensive than the prescriptive solution were also found. Beyond the rather academic issue of their existence, they are of little interest. Consequently, unless specifically noted, no solution whose cost exceeds the prescriptive solution will be discussed in this section.

2 The total sprinklering alternative is included even though it is more expensive than the prescriptive solution in this case since totally sprinklering the entire building is a retrofit strategy considered in Section 3.2.2.

Table 3.15 Initial States Used in Case Study of the Prototypical Hospital

Building Safety Feature	Zone 2 Floor 1	Floor 2	Floors 3 Through 7
Construction	Non-Combustible Fire Resistive	Non-Combustible Fire Resistive	Non-Combustible Fire Resistive
Interior Finish (Corridor & Exit)	Class C	Class C	Class C
Interior Finish (Rooms)	Class C	Class C	Class C
Corridor Partition Walls	Between 20 Min. and 1 Hour	Between 20 Min. and 1 Hour	Less Than 20 Min.
Doors to Corridor	Less Than 20 Min.	Less Than 20 Min.	No Door
Zone Dimensions	No Dead End > 30' Length: 100'-150'	No Dead End > 30' Length: 100'-150'	Dead End Between 30' and 100'
Vertical Openings	Enclosed: Less than 1 Hour	Enclosed: Less than 1 Hour	Enclosed: Less than 1 Hour
Hazardous Areas	Double Deficiency in Zone	Double Deficiency in Zone	Double Deficiency in Zone
Smoke Control	Smoke Partition	No Control	No Control
Emergency Movement	Horizontal Exit	Multiple Routes: No Horizontal Exits	Multiple Routes: No Horizontal Exits
Manual Fire Alarm	Without Fire Dept. Connection	Without Fire Dept. Connection	Without Fire Dept. Connection
Smoke Detection and Alarm	None	None	None
Automatic Sprinklers	None	None	None

FIGURE 3.6

RETROFIT PACKAGES AND THEIR ASSOCIATED COSTS FOR ZONE 2 OF THE FIRST FLOOR

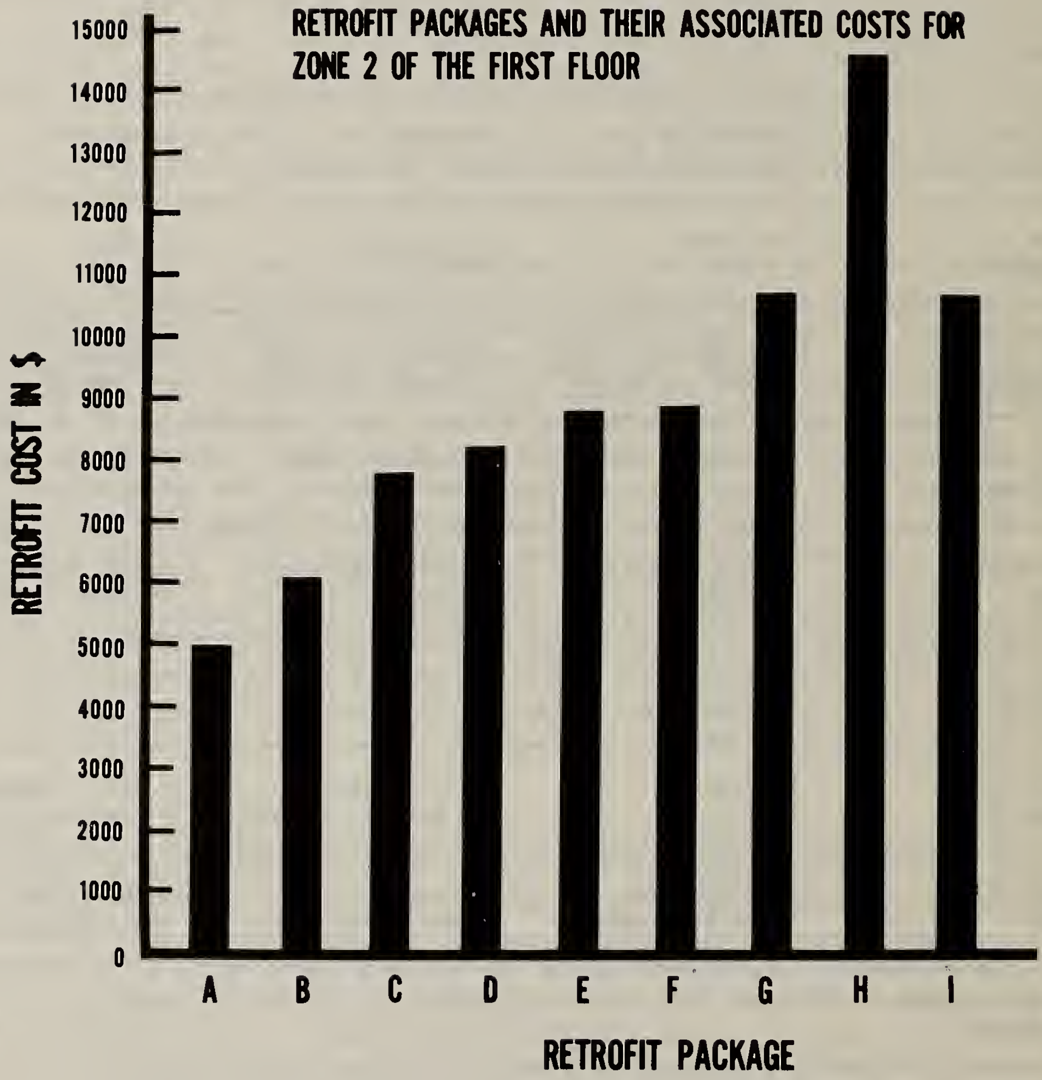

Table 3.16 Retrofit Packages for Zone 2 of the First Floor

Retrofit Package	Retrofit Description (Upgraded from the Initial State)	Surplus C	E	P	G	Retrofit Cost	Percent of Prescriptive
A	Interior Finish (C&E[a]): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies	5	0	5	11	4750	45.5
B	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Manual Fire Alarm: With Fire Department Connection	5	1	5	12	5750	55.0
C	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Automatic Sprinklers: Corridor	7	2	6	13	7550	72.2
D	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Smoke Detection and Alarm: Corridor	5	2	7	13	7900	75.6
E	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies	7	0	7	13	8500	81.3
F	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Vertical Openings: Enclosed Greater than 2 Hours Hazardous Areas: No Deficiencies	8	0	8	14	8650	82.8
G	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Greater Than 20 Min. Hazardous Areas: No Deficiencies	6	0	6	12	10450	100.0
H	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: Single Deficiency (in Zone) Automatic Sprinklers: Total Space	9	3	10	15	14310	136.9
I	Prescriptive	0	0	0	5	10450	100.0

[a] Corridor and Exit.

[b] If the initial state is above the prescriptive state, then the retrofit cost for that factor is zero.

[c] See Table 2.5 for a complete listing of the values of the safety parameters corresponding to strict compliance to the Life Safety Code in non-sprinkered facilities.

packages A and B are equal to about half the cost of the prescriptive solution, and that retrofit packages C, D, E and F cost approximately 25 percent less than the prescriptive solution.

The least-cost retrofit strategy indicated by Table 3.16 involves the upgrading of all interior finishes in the corridor and exits and in the rooms to a Class A flame spread rating and the removal of all deficiencies from hazardous areas within the fire zone. The cost of this retrofit strategy is shown to be approximately $4750 (or 45 percent of the prescriptive cost). In addition to being less costly, this strategy has a surplus score in three of the four redundancy requirements. The prescriptive solution has a surplus in only one of the four redundancy requirements, that of general safety. Surplus scores are indicated under the column headings C (Containment), E (Extinguishment), P (People Movement), and G (General).

Retrofit package B is the same as A with the exception that the manual fire alarm system has been provided with a connection to the fire department. This retrofit strategy costs approximately $5750 (or 55 percent of the prescriptive costs) and has the following surpluses: C, 5 points; E, 1 point; P, 5 points; and G 12 points. Row G of Table 3.16 shows that the retrofit strategy with the highest surplus in all four categories is to totally sprinkler the fire zone. This strategy, however, is almost 37 percent <u>more</u> expensive than the prescriptive solution.

Based on the preceding discussion it appears that retrofit packages A and B would seem to be the most attractive. This is due both to their cost advantage and their similarity. Note also that retrofit package A is contained in packages B through G.

<u>Second Floor Fire Zone</u>

An analysis of the second floor fire zone produces several important differences from the case just examined. In order to establish a reference point, the initial state for each of the 13 Building Safety Features in the second floor fire zone may be taken from the second column of Table 3.15. Entering the scores associated with the initial state of each of the 13 safety features into the appropriate places in Table 5 of the worksheet (see Exhibit 2.5) will show that in order to achieve compliance to the Life Safety Code net improvements of 22 points in containment safety, 11 points in extinguishment safety, 8 points in people movement safety and 16 points in general safety are needed.

As in the previous case, the input is the computerized procedure is summarized in Table 3.11 as the critical element counts. All critical element counts are based on the floor plans presented in section 3.2. Table 3.15 reveals that two of the 13 Building Safety Features on the second floor are in a lower state than in Zone 2 of the first floor. This has a significant impact on the admissible retrofit strategies generated by the computerized procedure. More succinctly, the number of admissible retrofits having a cost less than or equal to the prescriptive

FIGURE 3.7

RETROFIT PACKAGES AND THEIR ASSOCIATED COSTS FOR THE SECOND FLOOR

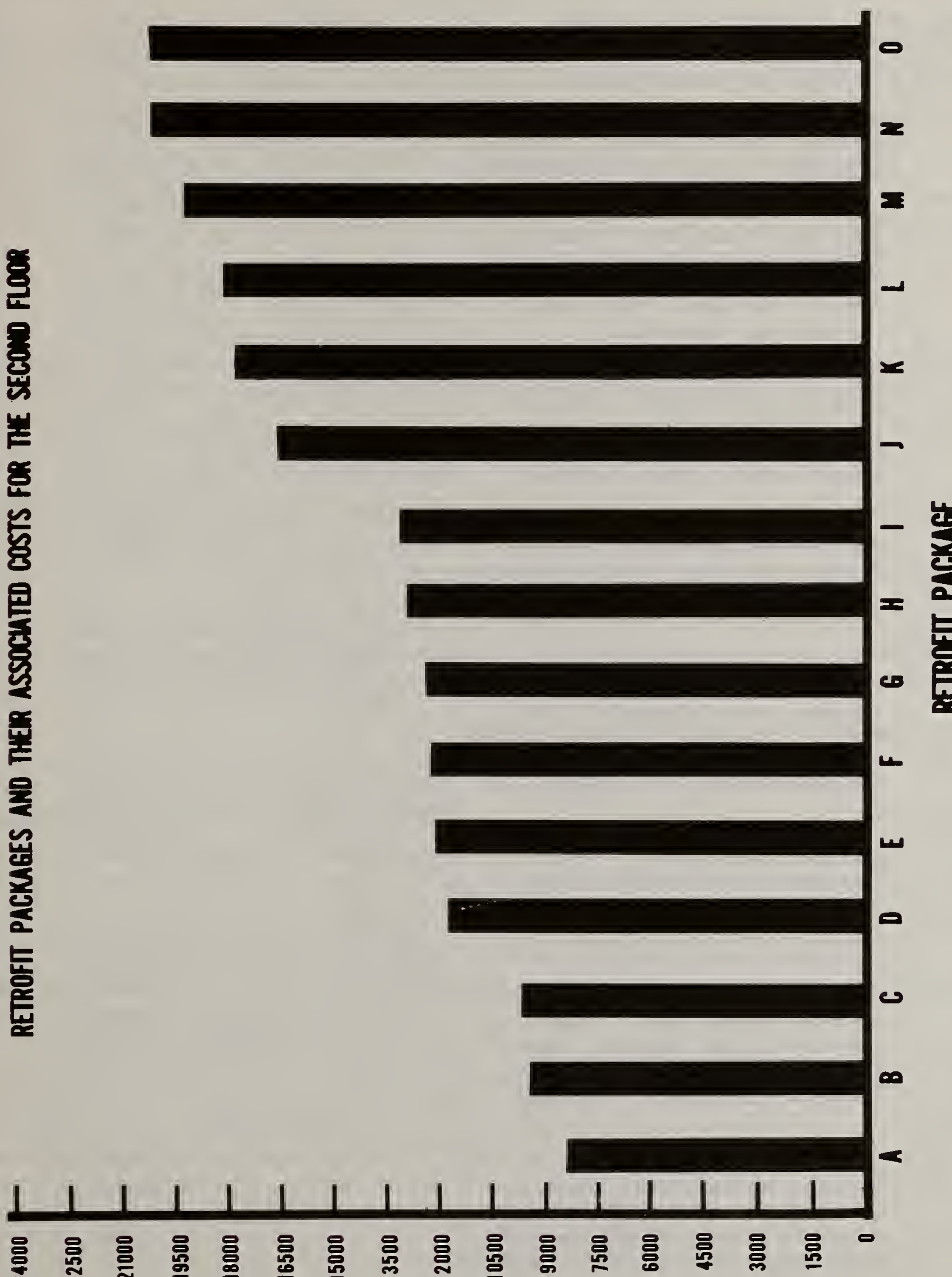

Table 3.17 Retrofit Packages for the Second Floor

Retrofit Package	Retrofit Description (Upgraded from the Initial State)	Surplus C	E	P	G	Retrofit Cost	Percent of Prescriptive
A	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies	3	0	0	8	8260	41.1
B	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Manual Fire Alarm: With Fire Department Connection	3	1	0	9	9260	46.0
C	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition	3	0	0	8	9660	48.0
D	Interior Finish (C&E): Class A Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: No Deficiencies	0	0	3	5	11560	57.5
E	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies	5	0	2	10	12010	59.7
F	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Vertical Openings: Enclosed Greater than 2 Hours Hazardous Areas: No Deficiencies	3	0	0	9	12160	60.5
G	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Automatic Sprinklers: Corridor	5	2	1	10	12260	61.0
H	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Smoke Detection and Alarm: Corridor	3	2	2	10	12760	63.5

Table 3.17 Continued

Retrofit Package	Retrofit Description (Upgraded to from the Initial State)	Surplus C	E	P	G	Retrofit Cost	Percent of Prescriptive
I	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Emergency Movement: Horizontal Exit	3	0	3	9	12910	64.2
J	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Doors to Corridor: Between 20 Min. and 1 Hour	4	0	1	9	16360	81.4
K	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: Single Deficiency (in Zone) Automatic Sprinklers: Corridor and Habitable Space	5	2	4	10	17915	89.1
L	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Greater Than 20 Min. and Automatic Closure Hazardous Areas: No Deficiencies	5	0	2	10	17980	89.4
M	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: Single Deficiency (in Zone) Automatic Sprinklers: Total Space	7	4	5	12	19040	94.7
N	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: Single Deficiency (in Zone) Manual Fire Alarm: With Fire Department Connection Automatic Sprinklers: Total Space	7	5	5	13	20040	99.7
O	Prescriptive	0	0	0	5	20110	100.0

solution has increased from 7 to 14. Furthermore, in this case the cost of totally sprinklering the fire zone is revealed to be less than the cost of the prescriptive solution. The difference in the costs of the two solutions, however, is very small (approximately 5 percent).

The 14 admissible retrofits, ranked from least costly to most costly, are included in a graphical summary of costs in Figure 3.7. Also included is the prescriptive solution and the package ID (a letter between A and N which corresponds to its (cost) rank). The prescriptive solution is plotted at the far right and is labeled "O". The height of the bars in Figure 3.7 denotes the expected retrofit cost of each strategy. The physical retrofit package associated with each identifying letter is defined in Table 3.17.

A close examination of Figure 3.7 reveals a distinct pattern in the costs of the retrofit packages. In particular, there are several plateaus around which from 2 to 6 retrofit strategies are grouped. The first plateau is approximately $9,000 and contains retrofit packages A, B and C. The second plateau is approximately $12,000 and contains retrofit packages D through I. Table 3.17 indicates that although retrofit packages D through I differ by less than $1,500, there are some significant differences in the factors which require treatment. This provides an example of how the provision of alternative solutions will enable decision makers to take into consideration the effects of non-construction costs, such as a potential reduction in services due to the upgrading of a particular factor (e.g., the installation of sprinklers in the corridor), on the retrofit decision. The third and fourth plateaus are centered around $17,000 and $20,000 and contain retrofit packages J, K, and L, and M, N, and O.

The least-cost means of achieving compliance according to Table 3.17 is to upgrade the flame spread rating on all interior finishes from Class C to Class A, and to remove all deficiencies from the hazardous areas within the fire zone. This retrofit strategy would cost approximately $8,260 (or 41.1 percent of the cost of the prescriptive solution). In addition, this package has a surplus of 3 points in containment safety and 8 points in general safety while the prescriptive solution has no surplus in containment safety and only 5 points in general safety. A similar pattern of surpluses is revealed in retrofit packages B and C. (Retrofit packages B and C do not differ significantly from retrofit package A.) The increases in surplus in the four safety categories (C, E, P and G) are modest until the fourth plateau, retrofit packages M and N, is reached. Although these packages have high surpluses (C=7, E=4 to 5, P=5, G=13) they are almost twice as expensive as the basic packages A, B and C. In this case it appears that unless the decision maker has some strong _a priori_ belief about the need for a particular retrofit (e.g., total sprinklering) it would be prudent to opt for one of the more basic packages.

Patient Floor Fire Zones (Floors Three Through Seven)

The analysis of the fire zone for a patient floor highlights the claim that the Fire Safety Evaluation System can be both economical and flexible. In order to establish a reference point, the initial state for each of the 13 Building Safety Features, for the third fire zone is obtained from the last column of Table 3.15. Entering the scores associated with the initial state of each of the 13 safety factors into the appropriate places in Table 5 of the worksheet (see Exhibit 2.5) shows that in order to achieve compliance to the Life Safety Code, net improvements of 33 points in containment safety, 11 points in extinguishment safety, 24 points in people movement safety, and 36 points in general safety are needed. As in the two previous cases, the input for the computerized procedure is summarized in Table 3.11 as the critical element counts. All critical element counts are based on the floorplans presented in Section 3.1. Reference to Table 3.15 indicates that five features (Corridor Partition Walls, Doors to Corridor, Zone Dimensions, Smoke Control, and Emergency Movement Routes) are in lower states than they were for Zone 2 of the first floor. (Three features are in a lower state than for the second floor fire zone.) This has as an implication that more potential retrofit strategies exist (some of which will be admissible) than for the second zone of the first floor or for the second floor.

In the computer studies for the patient room floors, 20 distinct admissible retrofit strategies were found that were less expensive than the prescriptive solution. These 20 retrofit strategies took on values between $20,000 and $35,000 per floor; the cost of the prescriptive solution is approximately $38,000 per floor. The 20 admissible retrofit strategies, ranked by cost, are assigned a package ID between A and T depending on their (cost) rank. The 20 admissable retrofit packages are plotted in Figure 3.8 along with a twenty-first package, the prescriptive solution, which is labeled as "U".

It is revealed by Figure 3.8 that the costs of the retrofit packages rise very slowly. For example, nine retrofits (A through I) are expected to cost less than $25,000 per floor; four more are expected to cost between $25,000 and $27,000 per floor. The large number of low-cost[1] retrofit strategies should facilitiate the tailoring of technical solutions to the fire safety problem to the operational characteristics of a particular health care facility. The opportunities for combining the technical aspects of sound design judgment with criteria on the provision of services becomes more clear when Table 3.18 is examined in some detail. For example, decision makers who wish to preclude the installation of automatic sprinklers in patient use areas and yet achieve cost savings of 35 percent or more over the prescriptive solution would still have six retrofit packages from which to choose. Another important piece of information gleaned from Table 3.18 is that totally sprinklering the fire zone

[1] Low cost implies a cost saving potential of 35 percent or more over the cost of the prescriptive solution.

FIGURE 3.8

RETROFIT PACKAGES AND THEIR ASSOCIATED COSTS
FOR THE THIRD THROUGH SEVENTH FLOORS

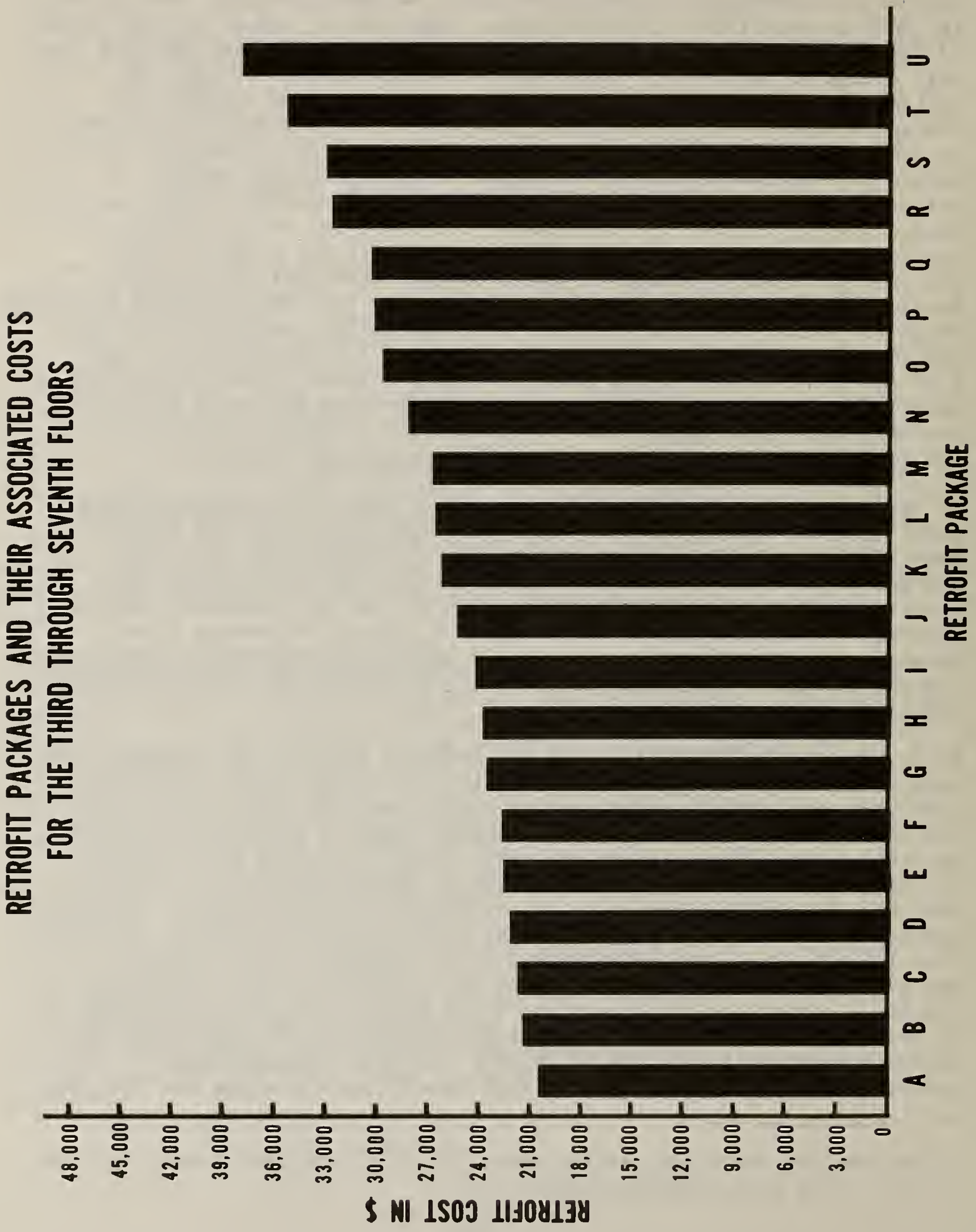

Table 3.18 Retrofit Packages for the Third through Seventh Floors

Retrofit Package	Retrofit Description (Upgraded from the Initial State)	Surplus C	E	P	G	Retrofit Cost	Percent of Prescriptive
A	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Emergency Movement: Horizontal Exit	5	0	2	6	20403	53.7
B	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Emergency Movement: Horizontal Exit Manual Fire Alarm: With Fire Department Connection	4	1	1	6	21253	55.9
C	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Automatic Sprinklers: Corridor and Habitable Space	4	2	0	2	21740	57.2
D	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Exclosed Greater Than 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Automatic Sprinklers: Corridor	7	3	0	6	22153	58.3
E	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Smoke Detection and Alarm: Corridor	4	3	0	5	22503	59.2

Table 3.18 Continued

Retrofit Package	Retrofit Description (Upgraded from the Initial State)	Surplus C	E	P	G	Retrofit Cost	Percent of Prescriptive
F	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Smoke Detection and Alarm: Corridor	5	3	1	6	22653	59.6
G	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Automatic Sprinklers: Total Space	6	4	1	4	23453	61.7
H	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Corridor Partition Walls: Between 20 Min. and 1 Hour Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: No Deficiency Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Smoke Detection and Alarm: Corridor	6	3	1	7	23853	62.8
I	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Greater Than 20 Minutes Vertical Openings: Enclosed Greater than 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection	6	1	0	5	24153	63.6
J	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: No Deficiencies Manual Fire Alarm: With Fire Department Connection Smoke Detection and Alarm: Corridor Automatic Sprinklers: Corridor	7	5	0	6	25253	66.5

Table 3.18 Continued

Retrofit Package	Retrofit Description (Upgraded from the Initial State)	SURPLUS C	E	P	G	Retrofit Cost	Percent of Prescriptive
K	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Smoke Detection and Alarm: Corridor Automatic Sprinklers: Corridor and Habitable Space	4	4	2	4	26240	69.0
L	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Smoke Detection and Alarm: Corridor Automatic Sprinklers: Corridor	6	5	1	7	26503	69.7
M	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Automatic Sprinklers: Corridor and Habitable Space	4	3	0	3	26640	70.1
N	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Zone Dimensions: No Dead End Greater Than 30' Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection	2	0	0	4	28253	74.3
O	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Smoke Detection and Alarm: Rooms	5	3	2	6	29776	78.4

Table 3.18 Continued

Retrofit Package	Retrofit Description (Upgraded from the Initial State)	Surplus C	E	P	G	Retrofit Cost	Percent of Prescriptive
P	Interior Finish (C&E): Class B Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Smoke Detection and Alarm: Corridor Automatic Sprinklers: Corridor and Habitable Space	4	4	2	4	30140	79.3
Q	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Detection and Alarm: Corridor and Habitable Space	4	4	0	4	32726	86.1
R	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Zone Dimensions: No Dead End Greater Than 30' Vertical Openings: Enclosed Between 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection	4	1	2	7	33003	86.8
S	Interior Finish (C&E): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Emergency Movement: Horizontal Exit Smoke Detection and Alarm: Corridor Automatic Sprinklers: Total Space	1	6	1	4	34323	90.3
T	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Enclosed Greater Than 2 Hours Hazardous Areas: No Deficiencies Smoke Detection and Alarm: Total Space	5	5	2	6	35328	93.0
U	Prescriptive	0	0	0	2	38003	100.0

is, in this case, a very attractive retrofit, because it can be totally sprinklered for approximately $23,450 (or about 62 percent of the prescriptive solution's cost). The least-cost solution for this fire zone is approximately $20,400 (or about 54 percent of the prescriptive solution's cost).

Another result which clearly stresses the cost saving potential of the Fire Safety Evaluation System, is that the cost of removing the dead end corridor through the installation of an exit stairwell can be achieved at a 25 percent lower cost than for the prescriptive solution. Since the exit stairwell is one of the most expensive retrofits, it is reassuring to see that decision makers who have a strong preference for the removal of dead end corridors can use the Fire Safety Evaluation System to cut costs dramatically.[1]

3.2.2 Alternative Retrofit Strategies for the Entire Hospital

The focus of this section is on how the admissible retrofit strategies identified in the previous section can be synthesized into a comprehensive retrofit strategy for the entire building. In order to begin this process it is necessary to refer once more to Table 3.18. Of the 21 packages shown in this table at least seven show promise for incorporation into a comprehensive retrofit strategy. That is they are quite similar to an admissible retrofit for Zone 2 of the first floor and the second floor fire zone. These retrofits and a brief descriptor are defined as follows:

(1) 3A: Least Cost;
(2) 3B: Least Cost Plus Fire Department Connection on Manual Fire Alarms;
(3) 3D: Sprinklers in the Corridor;
(4) 3E: Smoke Detection and Alarm in the Corridor;
(5) 3G: Total Sprinklering;
(6) 3N: Removal of the Dead-End Corridor; and
(7) 3U: Prescriptive Solution.

As indicated in the previous section, the seven retrofit strategies were ranked from least costly to most costly and a package ID was assigned to each which was indicative of its (cost) rank. Figure 3.9 is a graphical summary of the costs of the alternative retrofit strategies. Table 3.19

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[1] The above statement is based on the prototypical hospital design and thus requires some qualification. If the configuration of the fire zone were such that several exit stairwells would have to be installed <u>and</u> the decision maker insisted on their installation then the cost saving potential of the Fire Safety Evaluation System would be significantly reduced. However, if the fire zone configuration required several exit stairwells to be installed and the decision maker did not insist on the installation of the exit stairwell, then the Fire Safety Evaluation System could be used to identify admissible retrofits which cut costs significantly (perhaps more than 50 percent).

FIGURE 3.9

Retrofit Packages and Their Associated Costs for the Entire Building

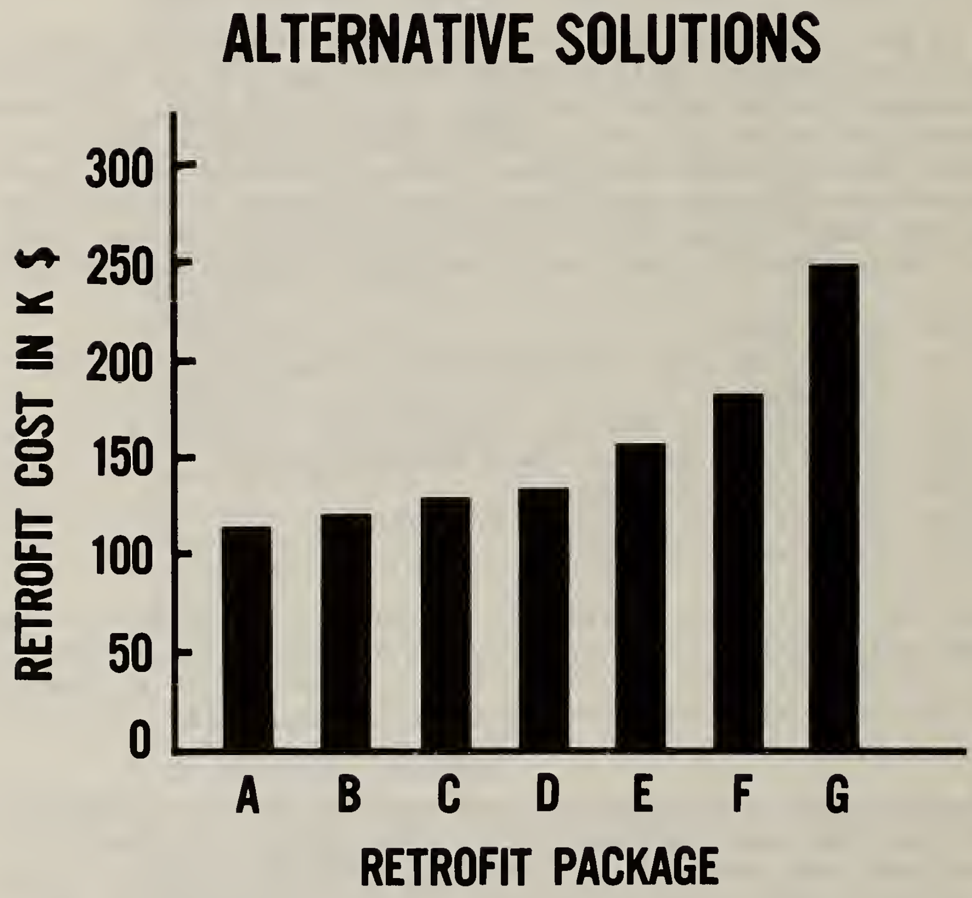

Table 3.19 Retrofit Packsges for the Prototypical Hospital: Floors One Through Seven

Retrofit Package	Zone 2 First Floor		Second Floor		Third Through Seventh Floors		Add Ons	Total Retrofit Cost
	Retrofit Description	Cost	Retrofit Description	Cost	Retrofit Description	Cost		
A	Interior Finish (C&E) Class A Interior Finish (Rooms): Class A Hazsrdous Areas: No Deficiencies	4750	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies	8260	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Verticsl Openings: Creater Than 2 Hours Hazsrdous Areas: No Deficiencies Smoke Control: Smoke Psrtition Emergency Movement: Horizontal Exit	102015	0	115025
B	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Manual Fire Alsrm: With Fire Department Connection	5750	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Manual Fire Alsrm: With Fire Department Connection	9260	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Between 1 and ? Hours Smoke Control: Smoke Psrtition Emergency Movement: Horizontsl Exit Manual Fire Alarm: With Fire Department Connection	106265	0	121275
C	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Sprinklers: Corridor	7550	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Sprinklers: Corridor	12260	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Minutes Vertical Openings: Greater Than 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Sprinklers: Corridor	110765	0	130575

Table 3.19 Continued

Retrofit Package	Zone 2 First Floor		Second Floor		Third Through Seventh Floors		Add Ons	Total Retrofit Cost
	Retrofit Description	Cost	Retrofit Description	Cost	Retrofit Description	Cost		
D	Interior Finish (C&E) Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Smoke Detection and Alarm: Corridor	7900	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies Smoke Detection and Alarm: Corridor	12760	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Min. Vertical Openings: Between 1 and 2 Hours Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection Smoke Detection and Alarm: Corridor	112515	0	133175
E	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: Single Deficiency (in Zone) Sprinklers: Total Space	14310	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: Single Deficiency (in Zone) Sprinklers: Total Space	19040	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Min. Hazardous Areas: Single Deficiency (in Zone) Smoke Control: Smoke Partition Sprinklers: Total Space	117265	7000	157615
F	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies	4750	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Hazardous Areas: No Deficiencies	8260	Interior Finish (C&E): Class A Interior Finish (Rooms): Class A Doors to Corridor: Less Than 20 Min. Zone Dimensions: No Dead Ends Greater Than 30' Hazardous Areas: No Deficiencies Smoke Control: Smoke Partition Manual Fire Alarm: With Fire Department Connection	141265	30000	184275
G	Prescriptive	10450	Prescriptive	20110	Prescriptive	190015	30000	250575

defines the scope of each of the seven total facility retrofit strategies and shows their costs. A wide range in retrofit costs is indicated by Figure 3.9 beginning with the more basic packages A, B, C and D and proceeding through to the more restrictive packages E (Total Sprinklering), F (Exit Stairwell), and G (Prescriptive). Figure 3.9 also reveals that retrofit costs for the entire facility range from approximately $115,000 to $250,000.

It is important to note that retrofit strategies E, F, and G, have added costs which were not counted in the computer study. The first add-on cost is associated with the assumption that it was possible to totally sprinkler a floor with the existing water supply. Although this assumption is reasonable for a single zone (floor) it is not reasonable in the case of totally sprinklering the entire building. In order to ensure that an adequate water supply is available for all zones, it would be necessary to run two high pressure (2.5 inch) lines up through two of the three exit stairwells. This fact accounts for the $7,000 add-on cost listed against retrofit strategy E. For retrofit strategies F and G, the cost of the exit stairwell was not included in the cost calculations for the prescriptive solutions for the first and second floor fire zones. (Both floors had no dead ends greater than 30 feet, and the corridor length was between 100 and 150 feet.) For both the first and second floor, it is assumed that the exit stairwell can be installed at a cost of $15,000 per floor. Hence the $30,000 add on for retrofit strategies F and G.

Based on the preceding discussion, it appears that the technical approach which offers the most promise for solving the fire safety problem in the prototypical hospital is to opt for one of the first four packages. The final choice in an actual case, however, may not be that simple. It will require close coordination among health care facility decision makers and their architectural and engineering advisors.

This concern is borne out by noting that the expected retrofit costs of packages A through D differ by less than $18,000. Therefore it is essential that careful consideration be given to the effects of non construction costs on the retrofit decision. It is important to note out that non-construction costs include not only lost revenues and a reduction in the level of services, but insurance differentials and operating and maintenance costs as well. Since these costs may be significant and do not always occur at the same time as the retrofitting activities are being carried out, one would ideally like to base the selection of a particular retrofit strategy on an established building investment technique such as life cycle costing. The current procedure does not do this.

Although the lack of this desirable attribute is unfortunate, the present approach does sharpen the focus of the decision maker considerably. In particular, by promoting fire safety in health care facilities through the use of the Fire Safety Evaluation System it becomes possible, by identifying and quantifying the cost impacts of the Life Safety Code, to tailor the solution of the fire safety problem to the particular needs and objectives of the user.

The emphasis on cost containment should focus not only on construction costs but on changes in revenues, operating, maintenance and insurance costs as well.

4. SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

4.1 SUMMARY

The identification of cost-effective levels of fire safety in health care facilities is a major concern to hospital administrators, fire safety engineers and public policy makers. Rising construction and operating costs coupled with more stringent building codes and continuing advances in medical and building technology have complicated the issue, forcing health care facility administrators to assess carefully the alternative means through which they can design, construct or update their facilities.

This study has focused on one aspect of the fire safety problem in health care facilities; the use of the Fire Safety Evaluation System developed by the Center for Fire Research at the National Bureau of Standards for determining equivalence to the Life Safety Code. The Life Safety Code, a voluntary code developed by the National Fire Protection Association, is currently the most widely used guide for identifying the minimum level of fire safety in buildings. Although the Life Safety Code may be thought of as prescriptive since it prescribes fixed solutions for life safety in designated occupancies, the performance concept can be explicitly introduced through a provision which allows for equivalent solutions. In light of this provision the National Bureau of Standards Center for Fire Research, through support from the Department of Health, Education and Welfare, has developed a system for determining how combinations of several widely accepted fire safety systems could be used to provide a level of safety equivalent to that required in the 1973 Life Safety Code. Using the Fire Safety Evaluation System as a measurement tool, this study describes a computerized procedure which helps identify the least-cost means of achieving compliance to the Life Safety Code. Since each of the parameters used in the Fire Safety Evaluation System has a unique value which corresponds to strict compliance, it is possible to quantify the cost savings attributable to the use of the Fire Safety Evaluation System over that of strict compliance. Preliminary studies conducted by the National Bureau of Standards have concluded that the use of a computerized version of the Fire Safety Evaluation System can result in cost savings of 50 percent or more over those associated with strict compliance to the Life Safety Code.

In addition to identifying the least-cost solution, the procedure also identifies from 10 to 20 retrofit alternatives, some of which are quite close in cost to the least-cost solution. The use of these retrofit alternatives is intended to facilitate the design selection process by providing information on relative costs as well as an opportunity to match common retrofit packages across fire zones. The use of alternatives can result in considerable savings of time in defining a comprehensive retrofit strategy for the entire building. In addition, the provision of retrofit alternatives should also simplify the problem of assessing the impacts of non-construction costs on the retrofit decision. The computerized procedure also contains a series of user options which make it possible to alter the cost of any retrofit, preclude a retrofit, force a retrofit to be included, or demand a higher level of safety than required by the Life Safety Code.

A prototypical hospital design was developed in order to illustrate how the computerized procedure would be used to solve actual fire safety problems. The prototypical hospital is patterned after a 300 bed general hospital built around 1960. The hospital is constructed with structural steel framing protected by a fire resistive concrete covering, reinforced concrete floors, fixed windows, and masonry exterior walls.

Application of the Fire Safety Evaluation System to the prototypical hospital indicated that all fire zones in areas of patient use, with the exception of the fire zone containing the emergency room, would require some type of retrofitting. Information on the scope and complexity of the retrofit alternatives was obtained from a series of floorplans for the prototypical hospital. This information was then used as input for the computerized procedure.

Results from the case study indicated that the prototypical hospital could be upgraded to achieve compliance to the Life Safety Code for approximately $115,000 if the Fire Safety Evaluation System is used. The cost of achieving compliance through adherence to the prescriptive provisions of the Life Safety Code would cost approximately $250,000. Although a significant portion of the cost of strict compliance to the Life Safety Code was due to the installation of an exit stairwell (to remove a dead-end corridor), it was found that the use of the Fire Safety Evaluation System could achieve compliance with the exit stairwell included in the retrofit package for approximately $185,000. Furthermore, the entire facility could be totally sprinklered for approximately $160,000 if the Fire Safety Evaluation System was used. These significant cost savings, even with high cost items included, are due to the inherent flexibility that the use of the Fire Safety Evaluation Systems offers to decision makers.

4.2 RECOMENDATIONS FOR FURTHER RESEARCH

In order to estimate the potential cost savings attributable to the use of the Fire Safety Evaluation System and to expand the present computerized procedure to include both a wider variety of health care facilities and the ability to generate solutions for more than one fire zone at a time, further research on several topics would be useful.

This study has concluded that cost savings of 50 percent or more over those associated with strict compliance are possible with the Fire Safety Evaluation System. The true cost saving potential of the Fire Safety Evaluation System, although substantial, can only be guessed at now. In order to quantify the cost saving potential of the Fire Safety Evaluation System, a regional survey of health care facilities would be useful. The emphasis of this survey could be on identifying a small set of "typical" hospitals and nursing homes in each of the nation's health regions. The initial conditions (states) of these health care facilities could then be assessed through use of the Fire Safety Evaluation System. Potential retrofits, including strict compliance to the Life Safety Code, could then be identified by fire safety experts in the field. All waivers which would normally be granted should also be documented. Cost engineering techniques could then be used to estimate the relevant retrofit costs. The information on the initial states, the potential retrofits and their costs could then be used to estimate the cost saving potential of the Fire Safety Evaluation System by facility type.

It is important to point out that the procedure described in this report focuses on identifying the least-cost combination of retrofits for a single fire zone in a health care facility. Most health care facilities, however, will usually contain several interconnected fire zones. Consequently, the installation of certain retrofits may affect the performance of some retrofit measures in other fire zones. These interdependencies are not explicitly dealt with when each fire zone is analyzed individually.

Taking these interdependencies into consideration would most likely result in further cost reductions through economy of design and construction.

The costs currently being used in the computerized procedure are location, time and facility dependent. It would be useful to have a straightforward means for adjusting costs to different locations and times as well as for different facility types. Cost engineering techniques could be used to develop a parametric procedure for estimating retrofit costs. This approach has an advantage over the use of straight average cost figures in that it permits local market conditions and the condition of the building to register their effects on anticipated retrofit costs. Such an approach thus allows the user to adjust costs systematically to a particular time and location and to estimate costs for a wide variety of facility types. Emphasis should also be placed on incorporating established building investment techniques, such as life-cycle costing, into the computerized procedure.

APPENDIX A

Unit Pricing Information

The unit pricing information presented in this section is based on anticipated costs in the Washington, D.C. area for the last quarter of 1978. These figures are used as a resident element cost matrix for the computerized procedure discussed earlier in the report. They can be used to identify the least-cost combination of the retrofits for a single zone as well as the costs of strict compliance and any alternative retrofit strategies. It is important to point out that the unit prices presented in this section are adequate only for the purpose of budget planning prior to the request for construction design. The actual cost estimates for a particular retrofit strategy will have to be made following the completion of the retrofit specification, design and material selection, and the establishment of the date of retrofits. Most of the unit pricing information presented in this section was either obtained from the Central Office of the Veteran's Administration or the Building Construction Cost Data 1978 booklet published by the Robert Snow Means Company, Inc. The unit prices are IN-PLACE PRICES which include: demolition, waste removal, building materials, labor, installation and finishing, refinishing of adjacent areas and a markup for contractor overhead and profit. Similar unit pricing information can also be developed by local estimators for various retrofit strategies at specific locations. This information can be used to redefine the element cost matrix. For a more complete discussion the interested reader is referred to the companion report, A Computerized Approach for Identifying Cost-Effective Retrofits in Health Care Facilities. The unit pricing information used in the study is given as follows:

Coat with Fire-Retardant Paint	$0.40 Per Square Foot; (PSF)
Fireproof with Intumescent Mastic	
1/8" thick, 3/4 hour	$1.30 PSF
3/16" thick, 1 hour	$2.70 PSF
7/16" thick, 2 hour	$3.90 PSF
Fireproof Existing Wood Panel	$0.50 PSF
Replace Carpeting	$1.60 PSF
Install Drywall Including Painting	
1/2" thick	$0.75 PSF
5/8" thick	$0.80 PSF
Replace Door to Achieve 20 Minute or More Fire Resistance	
4'x7' door and hardware	$ 300 each
4'x7' door, frame and hardware	$ 700 each
7'x7' door, frame and hardware	$1100 each
Add automatic closing device	$ 60 each

Replace Door to Achieve Class B & C Fire Rating	
4'x7' door and hardware	$ 450 each
4'x7' door, frame and hardware	$1,250 each
7'x7' door and hardware	$ 800 each
7'x7' door, frame and hardware	$1,650 each
Replace Door to Achieve Class A Fire Rating	
4'x7' door and hardware	$ 500 each
4'x7' door, frame and hardware	$1,300 each
7'x7' door and hardware	$ 900 each
7'x7' door, frame and hardware	$1,750 each
Replace Ordinary Glass Light With Wire Glass Light	$ 40 each
Replace Defective Latch	$ 60 each
Replace Window Frames in Corridor Partition Walls (1000 square inches)	$ 400 each
Add Corridor Partitioning (8' wide) With Fire Door	
Class B and C Rating	$3,800 each
Class A Rating	$3,900 each
Provide Partition Extension (average 3' high) From Existing Partition to Structural Slab Above	$ 30 Per Linear Foot; (PLF)
Install Coded Manual Fire Alarm Station	$ 140 each
Connect Existing Manual Fire Alarm Stations to Fire Department	$1,000 Per Fire Zone
Install Detectors, Photoelectric and Ionization	$ 2.25 PSF
Install Magnetic Door Release Each Leaf	$ 425 each
Install Sprinklers in Nonhazardous Areas	$ 2.00 PSF
Install Sprinklers in Hazardous Areas	$ 2.25 PSF

Add a Fire Alarm to the Sprinkler	$ 225 each
Install Halon Head for Mechanical and Electrical Areas	$ 8,000 each
Add External Stairwell for Exit	$15,000 Per Floor

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

This study focuses upon one aspect of the fire safety problem in health care facilities; the use of the Fire Safety Evaluation System developed by the Center for Fire Research at the National Bureau of Standards for determining equivalence to the Life Safety Code. The Life Safety Code, a voluntary code developed by the National Fire Protection Association, is currently the most widely used guide for identifying the minimum level of fire safety in buildings. Using the Fire Safety Evaluation System as a basis, this study develops a computerized procedure which permits the least-cost means of achieving compliance to the Life Safety Code in health care facilities to be identified. Since each of the parameters used in the Fire Safety Evaluation System has a unique value which corresponds to strict compliance, it is possible to quantify the cost savings attributable to the use of the Fire Safety Evaluation System over strict compliance to the Life Safety Code. Preliminary studies conducted by the National Bureau of Standards of a prototypical hospital have concluded that the use of this computerized procedure can result in cost savings of 50 percent or more over those associated with strict compliance to the Life Safety Code.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Applied economics; building codes; building economics; economic analysis; fire safety; health care facilities; hospitals; life safety; mathematical programming; nursing homes; renovation.

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