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Selecting Rail Properties for Improvement: A Plan for Analysis

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Technical Report to
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ABSTRACT

Section 901-(6) of the Railroad Revitalization and Regulatory Reform Act of 1976 (PL 94-210) calls for a listing and prioritization of rail properties to be improved in order to permit high-speed operations. This report identifies key factors entering the choice of links for such upgrading, and formulates an analytical methodology (and implementation plan) to assist the decision process.

Key words: Combinatorial optimization; cost/benefit analysis; high-speed rail; mathematical models; modal split; network analysis.

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I. INTRODUCTION

Section 901 of the Railroad Revitalization and Regulatory Reform Act of 1976 (Public Law 94-210; Feb. 5, 1976) calls for selected studies directed toward the general goals of the Act, which are "to rehabilitate and maintain the physical facilities, improve the operations and structure, and restore the financial stability of the railway system of the United States, and to promote the revitalization of the railway system." Among these mandated studies is one which is to develop "a listing, in order of descending priority, of the rail properties which should be improved to the extent necessary to permit high-speed passenger or freight service over such properties, in terms of the costs and benefits of such improvements and the reasons therefor." The purpose of the present document is to propose a plan to implement that mandated study.

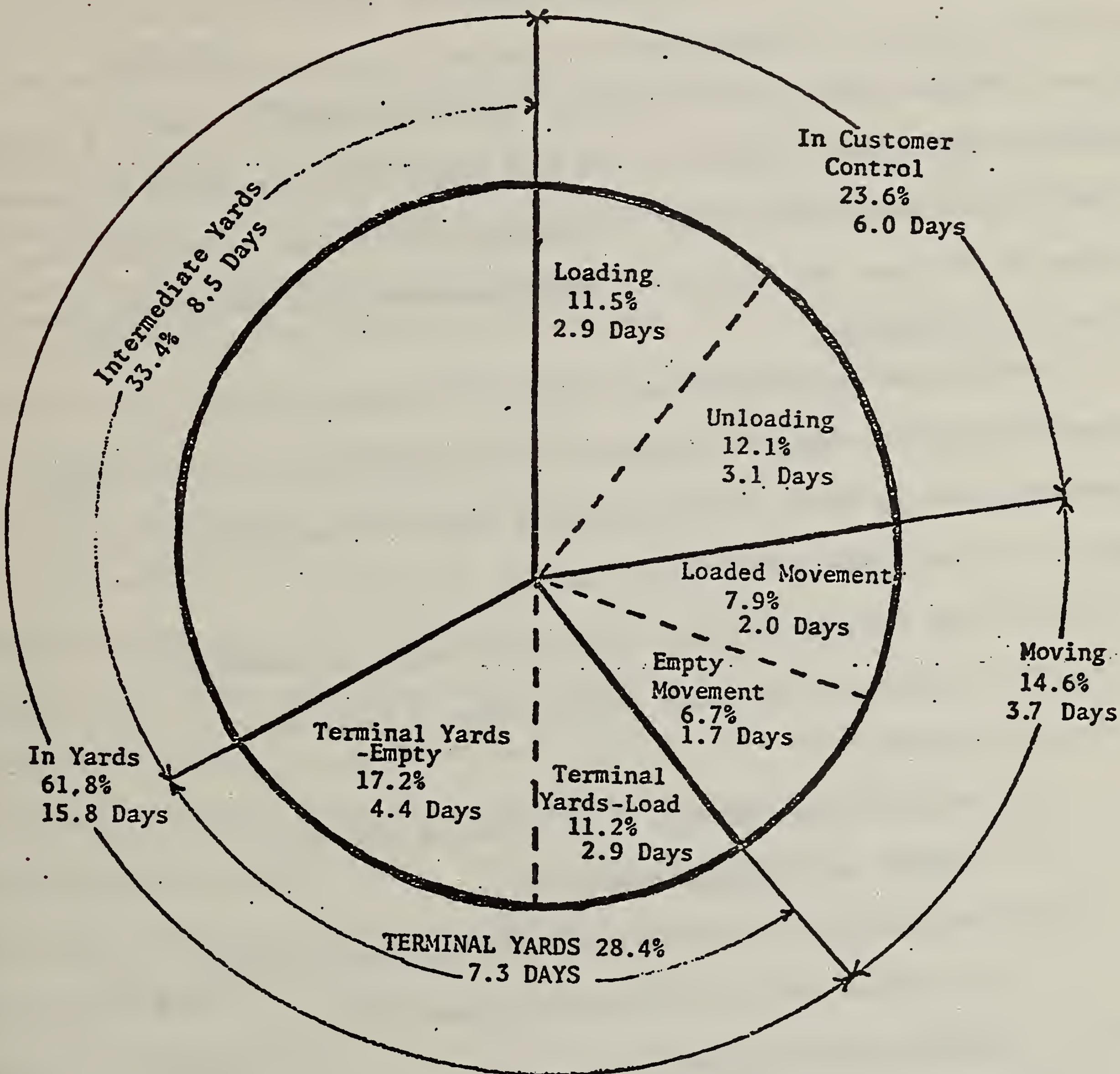
Throughout this study, primary emphasis has been given to analysis and discussion of freight service, with high-speed passenger service only considered insofar as it interacts with the proposed high-speed freight service. This approach has been chosen as the one best harmonizing with the stated overall goals of Public Law 94-210 with their stress on restoring the financial stability of the rail system. Because the freight service supplies the financial backbone of the rail system, it should be the controlling consideration in this study. In addition, a number of recent studies of high-speed passenger service have given the role of freight secondary consideration at best. The freight-orientation adopted here for the mandated study may in part balance these prior studies' emphasis on planning for high-speed rail service.

In designing the study, we have not restricted attention merely to those physical changes necessary to provide higher speeds for loaded and empty rail freight cars--although we do intend to provide a detailed analysis of such changes as will in fact promote higher speeds along the track. We have in general interpreted "high-speed service" to denote that service which, by whatever means, significantly reduces the current average (and, secondarily, the variability) of shipping times. Figure 1 illustrates the need for placing any meaningful study of expedited freight service in a context of changes in pick-up and distribution systems, and especially of improvements in terminal and intermediate-yard procedures.

The ideal methodology to be employed in the study would be cost/benefit analysis, which might in theory provide adequate criteria for a project-by-project ranking of selected properties down to an established cut-off point at some level of economic viability for the rail system. But, a detailed line-by-line analysis of the costs of rehabilitation and of the monetary and nonmonetary returns will not be possible within the time constraints of the mandated study. Therefore, we base our approach on a cost/revenue analysis supplemented with quantification-as-possible of supplemental costs and benefits, ranging from the relatively easy-to-evaluate effects of unpriced time savings to the more qualitative consideration required for certain environmental impacts.

Figure I-1

AVERAGE EQUIPMENT TRIP CYCLE



NOTES:

Average Cycle Time 25.6 Days

SOURCE:

Federal Railway Administration
Report: FRA-OE-73-1

II. SCOPE OF WORK

Section A. Background Information

On February 5, 1976, the Railroad Revitalization and Regulatory Reform (RRRR) Act was signed into law. Section 901 of this "Rail Act" directs the Secretary of Transportation to conduct a comprehensive study of the national railroad system. Section 901(6) calls for a study to produce a listing, in order of descending priority, of the rail properties which should be improved "to permit high-speed rail freight or passenger service over such properties, in terms of the costs and benefits of such improvements and the reasons therefor."

Section B. The Problem

The problem to be addressed is that of determining which rail properties should be improved in order to permit high-speed railroad freight or passenger service under various operating levels and assumptions. Key issues to be considered include the following:

1. The factors affecting high-speed freight and passenger operations, and their relationships to qualities of service.
2. The costs and benefits of facilitating high-speed freight and passenger operations.
3. The specific rail properties to be improved to permit high-speed service under varying assumptions.

Section C. Required Outputs of 901(6).

For each of various possible operating levels and assumptions, a listing (in descending priority by cost/benefit criteria) of railroad properties to be improved to permit high-speed railroad freight and passenger service.

Section D. Required Output of Project Phase Reported Here

A report (the present document) identifying critical elements of the problem, and developing a study plan and methodology which can be implemented to produce the set of listings described in item C above.

Section E. Approach

The study plan must be designed and develcped to take time and resource constraints into account, so that major emphasis is laid upon utilizing existing engineering and operational data and readily-available analytic tools.

Section F. Constraints of State-of-the-Art

State-of-the-Art constraints are binding at two points relating to the mandated 901(6) study: (i) with respect to existing data and software; and (ii) with respect to the operational technologies of existing railway rolling-stock. The justification for these constraints is the immediacy of the problem. U.S. railroads are in a crisis NOW. This crisis must be alleviated NOW. A means for identifying those properties on which cost and benefit considerations suggest priority for raising operating speeds is required as soon as possible so that needed action can be formulated promptly. The study is to be constrained to existing railroad technologies because of the large investments in the existing massive physical plant. Such a plant is capable of operation at a much higher level of service, one that will provide very satisfactory service to a great majority of users.

Section G. Definitions

1. Rail Properties. The usual connotation of "rail properties" is all the real property and rolling stock belonging to a railroad. For purposes of this report, however, rail properties are defined as trackage links (trackage between intersections with other trackage) and collections of such trackage. Other classes of properties are being addressed in other Section 901 studies.

2. High Speed. The appropriate definition of high speed is determined by the constraints imposed by use of existing railroad operating technologies. Extensive consultation with acknowledged rail experts suggested the operational definition of 60-80 miles per hour for freight service and 90-110 miles per hour for passenger service. This would permit continued use of most existing rolling stock. Higher freight speeds would cause excessive fuel consumption. Higher passenger speeds would preclude commingling of freight and passenger trains on the service trackage and would require development and acquisition of new rolling stock.

III. ELEMENTS OF THE PROBLEM AND ANALYSIS APPROACH

For this study of the key elements of high-speed rail service, a great deal of background information was obtained from a close review of the literature. A bibliography appears in Section VI. Also, many of the ideas mentioned result from discussions with the following people: J. Schofer, Northwestern University; C. Fisher, Federal Rail Administration; B. George, FRA Office of Safety; S. Ditmeyer, World Bank; H. Jones, Evaluation Technologies, Inc.; C. Hoppe, Booz, Allen & Hamilton; E. Dwyer, Union Switch and Signal; A. S. Lang and J. McLellan, Association of American Railroads; and T. Dyer and G. Hale, T. K. Dyer, Inc. Of course, neither these persons nor the firms, institutions, or agencies they represent, are responsible for our representation or interpretation of information gained from them.

Section A. General Considerations

Section A.1 Philosophy

The methodology proposed here directs itself to the selection of rail properties for upgrading for high-speed service; but it must be kept in mind that 901.(6) is only one section of the "Rail Act." The approach chosen, therefore, must accommodate the results of studies of other issues specified by the Act. Several of those studies (especially those of terminals and yards and of deferred maintenance) relate closely to the high-speed issue. In the present study, our emphasis will be on line-haul high speed, which we define as 60-80 miles-per-hour for freight and 90-110 miles-per-hour for passenger service. Other railroad operations that touch upon the high-speed issue will be treated in an aggregated or parametric way, to permit use of the results of other studies as they appear.

The rail properties treated here as candidates for upgrading are the line-haul links (or natural clusters of such links); thus appropriately detailed inputs are required for links now in the system. Specific links and aggregates of links will be ranked according to their feasibility for upgrading. Otherwise, the proposed models represent a macro approach to the upgrading problem. Costs incurred and benefits accrued will be attributed only to aggregated groups and/or geographic areas.

Since 1985 is the target date for the upgraded network, only incremental changes will be considered. This time limit precludes serious consideration of major long-term developments, such as plant relocations, changes in land use, alterations in regional development policies, technological changes, and major new induced demands. We must assume that tariffs and regulations will remain more or less constant, or that they will change rationally and coherently as a result of transportation policy. We do not consider the possibility that transportation policy might suddenly become subordinate to some other national concern, such as defense.

Since we expect the origin-destination markets for high-speed freight service to be different from those for high-speed passenger service, the goals of high speed for each may prove antagonistic. Should this antagonism manifest itself, we take it as our function in this study to treat the claims for high speed freight service as <u>superior</u>. This is consistent with the Rail Act's clear promotion of a rail system that is economically viable--or as nearly so as is commensurate with national needs. Economic health of the rail system must be based on freight revenues; the potential for profit in passenger operations is limited to a handful of corridors. However, certain benefits to passenger service should follow from the upgrading of trackage for faster freight service.

Section A.2 Data Considerations

This problem presents formidable data requirements. The number of links to be considered is very large, about 8800; and, for costing purposes, the required data for each link are numerous if comprehensiveness is to be attained. But such a situation is part and parcel of any costing process, and it is made no worse than usual by the approach we propose. Ideally, we would have at least enough information to calculate the cost to upgrade a chosen link to support several speeds faster than the current one. However, these very detailed engineering data do not exist and cannot be gathered within our time and resource limits. We must estimate such costs from whatever information is available on the current condition of the system and from what might be called "generic engineering data". The use of estimated costs carries some risk, but it is risk that cannot be avoided. The most we can do is hedge our bets whenever possible. Some of the procedures for doing this will be identified and described in Section B.2.

The data available for estimating benefits are more nearly adequate and appropriate to our purposes. The estimating procedure for these has strong traditions in the study of highway projects [1,2,3]; and the benefits in question tend to be aggregated.

Section A.3 Model Approach

In any competent modelling and analysis effort, some sensitivity analyses must be made even if both the structure and content of the data are well established. For the present problem, the usual sorts of sensitivity analyses are adequate for benefits, and usually so for operating costs. However the sensitivity analysis of capital costs requires special "meta-parametric" treatment. By this we mean that we not only suspect the numbers, but we are unsure how the costing should be structured. It might be necessary to consider a number of different structures in order to establish the "reasonable range" of capital cost estimates. Alternative capital costing procedures should be applied to candidate links. The exercise of the model might prove that benefits and costs are relatively insensitive to distinctly different capital cost structures, at least on a system basis. However, if the capital costs developed from alternative procedures are in disagreement, and the model proves sensitive to them, the disagreements must be reconciled. One of them must be accepted, or some way must be found to combine them.

Although we are preoccupied with line-haul links, the submodel structure we propose would also accept other types of components likely to be generated by concurrent studies. In anticipation of important results from the yard study, especially, more sophisticated treatment of yard and terminal activity will be possible and practical within the framework of the model structure. With some changes in the definition of the network, the model could be adapted to analyze the implications of upgrading only the yard or terminal facilities.

Section B. Costs and Benefits

Section B.1 Overview

It is very hard to define satisfactory measures of costs and benefits for a realistic evaluation of transportation policy alternatives. In a study with tight time limits, we cannot expect to make major advances in method or concept--advances needed for the satisfactory quantification of the totality of social costs and benefits. Therefore, throughout Section B we shall indicate where we can establish a cautious, common-sense reliance on established bodies of information.

Selecting properties for upgrading can be thought of as the reverse of selecting properties for abandonment. Therefore, we consulted the extensive methodology of the comprehensive "Phase II" rail plans developed within states for guidance in choosing useful cost-benefit categories. Plans from Pennsylvania [4], Michigan [5], and Iowa [6] were closely examined, and a cursory review was made of rail plans for other states. This survey, though illuminating, brought no direct solution to the problem. Quite naturally, given their purpose, these studies count heavily the direct effects of abandonment on shipper employment, railroad employment, and local tax bases, as well as indirect (multiplier) effects. Such effects, in the context of the whole economy, are mainly transfer payments--unsuitable for direct entry into a cost-benefit analysis at the macro level we envision.

It is clear that certain other effects must assume importance in a national study; these are strongly related to volume, transit time, reliability of transit time, revenues, and other matters associated with diversion between transportation modes. (The extent of such diversion, is critical in the areas of noise and air pollution, safety, and congestion.) The usefulness of the state studies is diminished in these regards because of the great differences in traffic densities between the segments considered for abandonment in those studies and those to be considered for upgrading in a national study.

A revenue output, calculated from the National Network's traffic approximating model, will be a direct output of our procedure and should serve as a basic measure of system viability. (However, if cost-revenue considerations alone justified improved service, the railroads quite possibly could already have attracted the capital to provide such service without government involvement.) Another benefit that can be computed fairly directly from this approach is the value of time and cost savings, insofar as that value is not reflected in revenues.

A considerable literature (mainly passenger studies [7,8,9,10]) is devoted to the money value of transportation time savings. Variants of procedures presented there can be applied to the valuation of freight time savings, although careful distinctions among categories of commodities to be shipped are necessary to make the results realistic. In many cases, the transportation pipeline is viewed as an extension of the warehousing facilities of both shippers and receivers. Predictability of departure and arrival times can be more important than a decrease of mean transit time. Therefore, an important benefit of upgrading for speed might be, not increased speeds as such, but the contribution of increased speeds to the reduction of the currently high variability of transit times.

The benefits of more predictable and less variable transit times are obvious, and are direct for shippers and receivers: predictable demurrage, more options as to order lead-time and inventory strategies, and direct cost savings. For the carriers themselves, the benefits are less certain and only indirect. Theoretically, predictability would allow innovations that would make rail freight service more attractive, especially for high-value, high-tariff commodities. Perhaps predictability would allow more operational flexibility in general, but the demand for predictability would in turn place further stresses upon the system. Presumably, these stresses would differ as much as railroads differ in their operational resources and adaptibility.

Section B.2 Classification Yards, Conditions of Roadways, Current Attainable Speeds, and Sources of Information

Section B.2.a Classification Yards

The time a freight car spends in a classification yard is virtually irretrievable. It is never made up by route speed. Therefore, the distribution of throughput times among yards, the possibility of by-passing yards, and the number of yards through which a car is likely to pass are all important in any study of the value of high-speed links.

Even on long hauls, a car is usually classified only a very few times (ranging from 1 to 3 or 4 in the Conrail system). However, Figure 1 shows that times spent in yards can be very long, averaging from 8-12 hours in "modern" yards [11,12,13,14,15] to more than twice that time in older yards. Utilization studies show that loaded cars spend nearly two-thirds of their time in yards and a correspondingly small portion of their time moving, often 10% and usually no more than 20%. (This effect is much greater for eastern roads.) Yards might be the most significant object of consideration in an effort to reduce transit time. Therefore, the greatest net contribution of upgrading for higher link speed might result from upgrading to support some speed less than the nominal high speed if current conditions are remarkably poor and speeds excessively slow. By treating yards as probabilistically parametrized impedances, it will be possible to combine shortest-path and Monte Carlo techniques to investigate what decreases in yard times are necessary if increased link speeds are to have a noticeable effect on system performance.

As to the data for such an analysis, railroads generally record throughput times in their own yards, but comprehensive national figures are unavailable. There are studies of single yards, and additional detailed case studies will be produced in the course of work required by Section 901.(2) being done by C. Hoppe at Booz, Allen & Hamilton. Also, there is methodology for simulation of yard operations (Stanford Research Institute [16], etc.), and substantial throughput data for major yards will be gathered for the 901.(2) study. Therefore estimates of current yard impedances and ranges of possible improvements should be available, either as outputs of 901.(2) or by study of better times at better yards-- or both.

Section B.2.b <u>Condition of Roadways</u>

Some segment-specific information on the current conditions of track and roadbed should be part of the process of estimating costs for upgrading. Ideally there should be an engineering study of each candidate link. Such information, however, is not available, and its acquisition would require time and money well beyond this study's limits.

Railroads know, or can ascertain, the condition of their own track and the FRA Office of Safety speed-limit classification of their own links; but this information does not now exist in a central data base.

Given these circumstances, and our time and funding limits, we are left to choose between modelling in a manner insensitive to current roadway conditions or determining and employing surrogates for those conditions. Two possible surrogates are (i) deferred maintenance and (ii) currently attainable speeds (discussed below in B.2.c).

It has been pointed out [17] that for the purposes of comprehensive policy analysis four existing studies of deferred maintenance have major deficiencies. The difficulty is simply that a consistent body of link-specific data cannot be derived from these studies. However, the preliminary report on deferred maintenance, pursuant to Section 504 of the Rail Act, is about to appear. From this report broad conclusions about roadway conditions might be drawn, using suitable assumptions about the distribution of deferred maintenance between main lines and branch lines. (Historical trends from the data bank of Thomas Dyer, Inc., might be helpful.) It may be supposed that the more viable railroads adequately maintain their main lines and that deferred maintenance is more common on branch lines. If this supposition is correct, a third surrogate for a link's current condition might be a combination of traffic volume and railroad financial condition. Though less precise than the other two surrogates, it can be supported from existing data bases. Link traffic volumes can be obtained from [18], ownership from the data base of the FRA network model, and railroad financial condition from Moody's.

B.2.c. Current Attainable Speeds

To upgrade a rail link for high speeds is to lower its minimum safe traversal time. Clearly some knowledge of currently attainable speeds is necessary in this study. Also, such speeds are a possible surrogate for the condition of roadways.

Railroads have working knowledge of the speed capabilities of their lines, and they must classify segments according to the FRA Office of Safety's six-step scheme (this need not be reported to a central authority). Speed is one of the parameters associated with a link in the FRA network model; but it is not available for every link, and is based on 1973 (or earlier) Office of Safety classifications. (These classifications change rapidly.)

The more viable railroads attempt to maintain segments to support the speeds promised by their timetables. Maximum link speeds are being inferred from timetables as part of the work done at Texas A&M University to augment the FRA network model (COTR: Carl Fisher; timetables collected by

Thomas Dyer, Inc.). Although the figures so generated will not be perfect, they will represent the railroads' operational goals. We cannot rely on them for the mandated study since the studies are concurrent.

B.3 Speed-Related Costs

Analyses of costs and benefits are to be made for several speeds, some higher than those common for current freight operations. Therefore, those costs which arise from or change substantially because of increased speeds require specific treatment. The pertinence of categories of costs depends on the mix of strategies used to assure high-speed service. Door-to-door transit time can be shortened (and/or its variance reduced) both by physical changes in the system and by changes in the procedures of pickup, sorting, and distribution. While direct relations of costs and speed of freight movement are not well worked out, they are less difficult to evaluate and allocate among freight movements than are the costs of procedural (operational) changes. An immediate effect of increased speeds should be the more efficient use of rolling stock. Long-range benefits should follow if rail management exploits the opportunities that improvements in trackage links afford for innovations in scheduling and marketing.

B.3.a Capital Costs

In this study it is useful to think of any investment in a roadway and its operating system as a capital cost if it is necessary before high-speed service can begin. (It should be noted that this does not conform to ICC accounting procedures, which do not, for example, treat the laying of track as a capital investment.) Such costs are primarily for track and roadbed and for signalling systems.

To estimate the costs of track and roadbed one would like a model that relates the current roadway-condition and topographical characteristics of a segment to the cost-per-mile of upgrading needed for various speeds. No such model exists, but there are cost studies of single projects [19,20], and certain organizations and individuals use rules of thumb, based on experience, to cost-out significant refurbishing. The FRA has estimated that on the average $250,000 is required to rebuild a mile of very poor track into a 60 mph, heavy duty line. Such information can be updated using the engineering price indices for the relevant inputs.

All in all, estimation of capital costs is the most difficult area in which to find information sufficiently precise, stable, and reliable to produce discriminant functions adequate for ranking among link-improvement candidates; and an engineering study with a cost-model output is beyond the scope of this study. However, after potential projects for upgrading are ranked according to their feasibility with reference to other costs and benefits, this difficulty will probably be eased. In some cases it should be clear that benefits are great enough to overwhelm simple cost considerations; in other cases, benefits will be so small that they could not justify even very low costs. Such judgments are easier to make within a range than they are to make of an isolated project.

The literature offers several studies concerned with costing the track and signalling improvements necessary for higher speeds. The first [21] treats both capital and operating costs on selected routes; and the second [22] includes a detailed study of capital costs for track and structures. The above studies are valuable, but their usefulness here is diminished because they deal with passenger service (which assumes high speeds and low tonnages inappropriate to a study of freight operations).

So far as signalling costs are concerned, basepoint information is contained in part in the FRA network model, of which the existing signalling system is a data element. Unlike track and roadbed costs, up-to-date estimates of costs for purchase and installation of centralized traffic control systems are available from suppliers.

B.3.b Maintenance Costs

The estimate of costs for upgrading rail segments for high-speed operations must consider consequent changes in maintenance costs. Given sufficient inputs, most of these can be assessed with the Transportation Systems Center's (TSC) cost model [23]. Although very little research has been done on speed-related costs of maintenance, that study indicates that maintenance-of-way is a weak quadratic function of operating speeds.

High speeds (and any resulting increase in volume) bring greater track wear and demand the more frequent replacement of track according to more rigorous standards. Wear increases on rolling stock also. However, if locomotives and cars spend less time on a given job and move from place to place more quickly, their greater productivity will be a countervailing factor to their increased wear; also, slow-moving stock will suffer less wear and move more safely over improved tracks and roadbeds.

B.3.c Energy Efficiency

Fuel costs can be estimated with one of several train performance calculator (TPC) computer programs [24]. The TPC developed and maintained by the Electromotive Division of General Motors has been used for this purpose. A preliminary examination of the results suggests a fuel consumption proportional to the 3/2 power of the speed when speeds are in the 60-120 mph range.

Naturally, the effect of speed on fuel consumption varies greatly with locomotive types, train configurations, and terrains. The speed of maximum operating efficiency varies from 70% of top speed for aerated engines to 95% of top speed for turbo-charged engines. In some configurations, aerodynamic effects are significant at speeds as low as 30 mph. Although increases in speed in the range below 25 mph can lead to improved fuel efficiency, increases above 35 mph cause increased fuel consumption. Consultation of standard engineering works (e.g. [25]) should help estimation in specific situations.

The application of overall gross statistics to a comparison of the energy costs of moving goods by rail and by truck[1] has produced, in several studies with differing assumptions, an estimate of 3.5 greater energy efficiency for rail movements [26]. (It must be emphasized that

[1]Railroads nominally compete with air and waterway modes as well. Time-tariff relations are such, however, that there is <u>no</u> direct competition between air and rail either at present or in any plausible scenario. Rail and water compete for certain low-value, low-tariff commodities. Any reasonable improvement in rail speed (unless accompanied by a tariff reduction) is not expected to affect the modal split greatly.

this is a gross figure.) A Project Independence [27] report for USRA uses a somewhat more refined methodology and suggests an upper bound of 2 as a more realistic estimate for the relative energy efficiency of rail (for diverted shipments).

It should be recalled that energy is expended not only to move revenue tonnage, but also to move the carrying vehicles themselves. In short trains, typical on many light-density rail branches, a high proportion of the energy goes to moving the locomotives alone. Further dead weight is added when company policy or state law requires cabooses. In a 1974 DOT comparison [28] of truck and rail fuel efficiencies in assorted hypothetical configurations, it was concluded that in some situations truck service is significantly more fuel-efficient than rail. The break-even point between the two modes varies both with length of train and with length of haul.

The assumptions of the comparison just mentioned have been criticized because they concern the diversion of branch-line freight, and its results probably do understate the energy advantages of rail in those situations which concern us.

Since the evidence suggests that the energy efficiency of rail relative to highway [29] varies greatly and might fall below unity, reliable information will require a detailed analysis based on distances and lot sizes, with at least a rudimentary classification of commodities.

Section C Diversion of Freight to Rail: Benefits and Disutilities

C.1 Fuel Consumption

In extreme cases fuel consumption for rail might be 1/3 or less that for highway. On the other hand, the per-unit fuel consumption on rail increases with speed, and becomes superlinear in the 60-80 mph range [30]. There is a trade-off: energy savings for much of the traffic diverted to rail against increased energy use for traffic already on rail. One way to assure savings would be to provide high-speed capabilities only to certain trains serving especially speed-sensitive shippers, perhaps with differential rates.

C.2 Air Pollution

If one considers only the "average shipment," the diversion of goods from truck to rail leads to a significant reduction of pollution emissions per ton moved. On the average, a ton moved by truck instead of rail produces six times as much carbon monoxide, 3.5 times as much oxides of nitrogen, 2 times as much particulate matter, and .5 times as much hydrocarbons [26].

Of course such figures must be affected by questions of energy efficiency, since pollution is essentially proportional to the fuel consumed. A detailed analysis may not ignore differences in truck type and performance. Energy efficiencies vary so much that it is reasonable to posit some category of freight movement for which trains would yield over 5 times more hydrocarbons than trucks.

For the evaluation of this cost-benefit element, it probably is adequate to extend and refine existing methods.

C.3 Noise

Real changes in noise pollution would result from the diversion of traffic from truck to rail. These changes are primarily rearrangements of the spatio-temporal distribution of noise sources and so they cannot be called improvements with any confidence. Indeed, the effect of noise pollution is, in general, a problem that so far resists useful quantification.

Trucks, per unit, are quieter than trains, but the same tonnage requires more trucks than rail cars. (The typical box car carries from 1.6 to 2.8 times the load of a typical trailer [26].) Also, truck routes are more pervasive of a community than rail routes, and the comparative noise effects of the different route patterns are hard to evaluate.

Several relevant and appropriate sources [31,32,33,34] have been identified. The last gives a particularly detailed analysis of comparative noise effects.

C.4 Safety

Improvements in track, roadbed, and signalling systems in themselves make rail transport safer; but higher speeds with greater volumes would be something of an offsetting factor. This complicated tradeoff is poorly understood--naturally enough, given our lack of experience with high-speed freight.

Using FRA Office of Safety accident literature (e.g., [35,36,37]), it is possible to make rough comparisons between accident figures for better-maintained and more poorly maintained track. Certainly track condition is a significant safety factor. The Northeast Corridor High-Speed Rail Passenger Service Improvement Project Task 6 Report notes that since the introduction of Metroliner traffic in 1969, the rate of freight train derailments in the Corridor has been 60% below the national average. In the same context, it should be noted [37] that in only a year a single railroad of modest size (Lehigh Valley) suffered derailment-related damage losses of over $650,000. Clearly, safety is no small economic matter.

Perhaps because they resist predictive analysis, safety issues seldom loom large in rail studies. However, in a high-speed study we must consider the safety problems attendant to multi-speed operations. It would be desirable to reduce grade crossings to a minimum on high-speed routes; and in that regard we must be aware of the fact that, even if such upgrading takes place, local speed regulations for crossings in populated areas could cancel at least some of the improvement in some link transversal times. (The inventory of grade crossings is available from the FRA Office of Safety and will be added to the network model from Texas A&M.) Given heavy tonnages at higher speeds, such operations as the flow of hazardous commodities through populated areas must be considered in a new light.

Although we can assume the safer movement of low-speed traffic over upgraded track, this system benefit cannot be said to offset increased employee injuries and fatalities if they are significant and directly related to increased speeds. It will be more dangerous for the public to intrude upon higher-speed links; also high speeds and volumes bring a greater likelihood of brush and forest fires caused by passing locomotives. To warn railroad personnel and the general public of increased dangers will have some cost--probably small and probably part of a larger safety information program.

The diversion of freight from truck to rail should lead to a reduction in the highway accident rate. A cost benefit analysis can use the Dyer methodology [24] to estimate the cost of holding safety on the upgraded system to the present system's standards, and then to evaluate any increased highway safety that can be attributed to the diversion of traffic to high-speed rail.

C.5 Effects on Users

For shippers now using rail transport, lower mean transit times could reduce inventory costs, especially if such costs include a daily interest rate applied to the value of a shipment. Also, shipments would not need to be planned so far in advance. To the extent that traffic is diverted from other modes to rail, increased volume could bring futher advantages, such as more frequently scheduled service.

Some shippers will lose the "warehouse" advantage of slow service, but the long range importance of this loss is doubtful. Warehousing is a somewhat unnatural use of transportation facilities; but if it is discovered that certain shippers need the "warehousing" advantage, special arrangements might be made--not as a function of line-haul operations but as a function of yard management.

A more awkward matter is the effect of higher speeds on rates. If higher speeds bring greater volume, and if greater volume permits lower rates, shippers (and perhaps their customers) will benefit. On the other hand, if higher speeds increase operating and maintenance costs, and if increased costs require higher rates, shippers to whom speedy shipment means little will suffer (as will their customers). Here again (as in C.1, above), perhaps some thought should be given to the provision of high-speed capabilities only to certain trains serving especially speed-sensitive shippers, perhaps with differential rates.

C.6 Employment

In abandonment studies it is common to divide effects on employment into those pertaining to railroad employment, direct (shipper) employment, and indirect (multiplier) employment. An uncertain amount of the gross total arrived at by these measures represent social transfers and should be omitted in a total cost-benefit analysis. The methodology developed by PIES [27] can be adapted to evaluate the residual effects on employment, if it is decided that they warrant inclusion in this study.

C.7 Highway Maintenance

Diversion of freight from highway to rail will have some effect on highway maintenance costs. Although not expected to be large, these effects should be considered in a cost-benefit analysis if they are quantifiable.

Section D. Model Concept

Several steps are involved in the proposed approach. The first involves an initial screening process to identify those network links which should be studied in greater detail. The aim of this step is to eliminate from further consideration the links which are unlikely under any reasonable scenario to be candidates for upgrading to high-speed status. Although these links may be used to provide connectivity and access to the main network, they will not have to be considered in the choice process, thereby cutting down the size of the problem.

Several procedures will be used to identify links which are candidates for study in greater detail. The use of multiple objective functions, both in the initial screening and in the optimization, reflects the fact that choice of links to upgrade involves many tradeoff decisions which may be in conflict. Is FRA aiming at improving the rail system to best serve its current customers, or trying to divert as much business as possible from other competing modes, primarily trucks? Or is the aim at the least costly system to meet a specified level of service, or trying to buy as much service as possible for a given budget level? Any of these goals is conceivable, and the initial screening should not eliminate links in such a manner as to preclude any of the corresponding scenarios.

One major initial effort will involve quantification of various costs and benefits associated with the current rail system and with possible upgrading of that system. As discussed earlier, much of the link-dependent data needed to calculate costs of improvement are not available because current track condition is not known. As a result, our approach is to develop models using available substitute data, such as current speeds, to estimate the appropriate costs. When better data are available, they can be substituted in the process for model-developed parameters. The link upgrading costs used in the models here will be general order-of-magnitude estimates. They are not based on terrain or other engineering details of the particular track segments since these are not available for the rail system as a whole. The possibility (cf. Section III B.2.b-c) of estimating current link condition from a combination of traffic level and the financial condition of the railroad will be explored.

After initial screening, the network data base, cost/benefit quantifications, and commodity predictions are to be inputs to the central optimization model. This model will, for various scenarios defined by input parameter values and optimization objectives, choose network links and combinations of links to be upgraded. The output of the central model will consist of several improvement projects, defined by the links to be improved and associated levels of improvement, one for each of the scenarios.

The central optimization model will consist of several submodules, each of which is itself a currently available model or procedure. Two steps form the basis for the central model, and its operation consists of alternating these steps until the link set to be improved remains constant from step to step. It is expected that this will occur in three to four iterations at the most, and if not, then manual alteration and analysis will be introduced.

The two steps in the central model are:

1. regarding link capabilities as "given", allocate traffic (by commodity class) among modes and then assign traffic to specific rail links;

2. for a given allocation and assignment of traffic, choose rail links to be improved.

The first step will use the Origin-Destination (O-D) commodity flow data, O-D travel times, and tariffs to compute the rail share of each O-D commodity flow. A link assignment of these flows will then be performed, probably using the FRA assignment programs. The second step will use link volumes and cost and benefit quantifications to choose rail links to improve. This step will utilize various versions of mathematical programming optimization models to select the projects for improvement.

After the central optimization model has been run for several different scenarios, the output link sets will be further analyzed for consensus, and a ranking of links to be improved will be produced. It is unlikely that ranking of each component of the link set will be required, since much of the cost and benefit data are at too gross a level to permit such detailed analysis of project alternatives. Thus the expected output of the modeling approach described here is a classification of links which differentiates degrees of desirability for multi-link improvement projects as a function of expected scenarios. The post-analysis of the link sets output from the optimization process will permit imposition of various operational factors which may not have been included explicitly in the optimizations. Possible examples include the assurance of contiguity of improvement projects, and inclusion of project-staging criteria in the link orderings. A summary of the costs and benefits associated with the link improvement projects will be prepared.

Although this process has not included rail improvements to permit high-speed passenger service, wherever improvements for freight service occur on links used for passenger service also, some benefit to the passenger service will accrue and will be tabulated. Since speeds for high-speed passenger traffic would be greater than for high-speed freight service and track improvements to permit high-speed service are different for the two, a separate analysis will be performed to ascertain where improvements in track might have an impact on passenger movements. This will build on previous passenger corridor analyses and focus on projected rail passenger share.

Figure III D.1 is a flowchart of the basic methodology to be employed. Models or processes required are shown in rectangular boxes; input data, in six-sided boxes; intermediate data bases indicated by parallelograms. The models and data required in the various stages -- initial screening and analysis, steps 1 and 2 of the central optimization model, and the link/project ranking and analysis -- are also listed in Table III D.1. The various sections of the flowchart and table will be referenced and discussed more fully in the next three sections.

Section E. Initial Analysis and Processing

E.1 Quantification of Costs and Benefits

Inputs to the central optimization model include numerical costs and benefits associated with improving rail links to allow high-speed operation. Two major benefits "drive" the optimization. The first of these is the amount (ton-miles) of traffic diverted from truck to rail by rail improvements. Since this represents a financial benefit to the railroads, the societal value of the additional revenues generated by those rail improvements is also important. A second benefit measure is the improved service represented by total time-savings (ton-hours) to those who ship. Additional benefits, such as energy savings, improved passenger service,

Figure III D.1: Flowchart of Basic Methodology

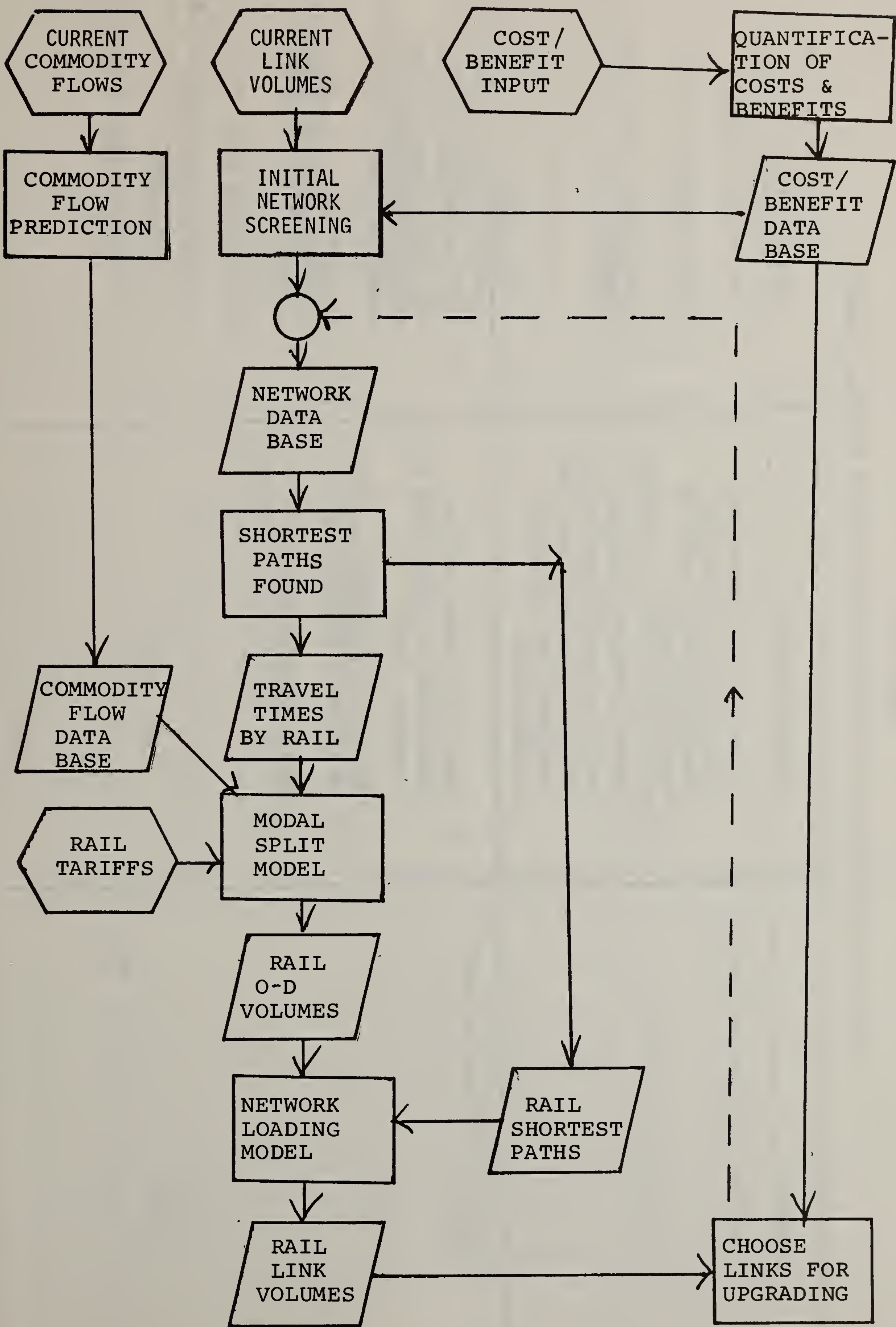


Table III-D.1

Models and Data Required for Analyzing High-Speed Rail Improvements

Stage	Models Required	Data Required
Initial Screening and Analysis	1. Commodity flow prediction model: method to identify commodities which could be shipped by rail. 2. Initial network screening model to identify what parts of the rail network are likely candidates for improvement to high speed.	1. Current link volumes 2. Current commodity flows 3. Rail tariffs by O-D and commodity
Central Optimization Model: Step 1	1. Modal split model and its sensitivity to travel time and commodity class 2. Network loading model and its sensitive to travel time 3. Yard throughput model	1. O-D tariffs and/or costs and travel times for rail and competing modes, by commodity class 2. O-D volumes by commodity class which are potentially shipped by rail 3. Rail network with a. link travel times and speeds b. yard throughput times

Table III-D.1 (Cont.)

Stage	Models Required	Data Required
Step 2	1. Benefit quantification model 2. Model of costs of improving links to high speed status, including both capital and operating costs 3. Model to select links to be improved under different scenarios	1. Current link condition (speed) 2. Link improvement capital costs 3. Operating cost changes resulting from high-speed improvements 4. Travel times achievable with high-speed improvements 5. Yard throughput times achievable (mean and variance) with improvements 6. Yard improvement costs 7. Link volumes by commodity class
Link/Project Ranking	1. Model to rank links on improvement potential	

better equipment utilization, reduced environmental pollution (primarily air and noise) and improved safety will be quantified, not on a link-by-link basis, but rather in general summary tables associated with particular link-improvement projects.

Quantifying benefits, though difficult, is not in this application as difficult as quantifying costs, a situation the opposite of that which normally occurs. As noted in Section III B.2, the main difficulty in computing the costs of improving rail links (track and signalling systems) is the lack of good data on the current condition of track. Because of known deferred maintenance policies and go-slow orders, the generally poor quality and deteriorating condition of track is known, but the actual extent and degree on any piece of track is not systematically recorded.

To get around the lack of direct data concerning the current condition of track, the best available data on several surrogates whose values are, or should be, correlated with track condition are to be used. The first of these is the average link speed available in the FRA rail network data base. It is known that there are serious difficulties with this data base, especially with the timeliness of the data, but it is the only one available on a sufficiently wide scale. Updates and additional data will be available from work being done now at Texas A & M, but are not expected to be available until September 1977. Some data on 2% of the links contained in the CONRAIL system were collected [38]. Though very good data on a sample of links in the system, they may only represent one type of system and may not be generalizable to the whole. In the absence of good data, it is necessary to use available data and modeling techniques such as regression analysis to relate the known link data and other characteristics, such as link volumes and railroad company financial viability, to estimate current link condition. Other models and information available in the T. K. Dyer report [21] may also be used in this analysis.

A final comment should be made. All this modeling is predicated on the assumption that the differences among the currently maintained qualities of different track links are large enough for there to be significant differences in the costs to improve the system to high-speed status. This may not be the case. Pieces of track may have sufficiently similar characteristics that cost differences depend primarily on link length with little variation resulting from track quality.

Operating costs for upgraded track must also be considered, since increased maintenance will be required to maintain high-speed service. The operating cost model contained in the Transportation Systems Center (TSC) report [23], which has speed as one of its parameters, will be used in estimating the increases in operating costs as a function of design speed.

E.2 Initial Network Screening

The FRA network model has approximately 8,800 links, but about 80% of them carry together less than one-third the total traffic [39].
Unless some of these offer especially attractive diversion potential, it is unlikely that these links will ever be considered for high-speed upgrading. The initial network screening process is designed to eliminate obviously poor candidates and to focus on obviously attractive candidates for upgrading.

One criterion for potentially desirable high-speed improvement is the possibility of diverting revenue-producing freight shipments from truck to rail. Thus part of the initial screening process will be the identification of markets in which a comparatively small change in rail transit time would result in a substantial increase in rail market share. There may not be any such markets; substantial travel-time reductions may be necessary to make rail competitive with truck transport. Any lesser travel time reductions will benefit current rail shippers but will not generate additional rail revenue. An initial examination of what level of travel-time change for various markets would shift, say, 5% of truck freight to rail, would identify any possible markets in which diversion is possible at all and would also indicate the level of improvement required.

Input to such an analysis would be a commodity-flow model, a modal split model, and transport impedances between zone pairs for the various modes. Several sources of commodity-flow data exist, including that of TSC [40], the Faucett study [41] and the National Network data base [42,43] The National Networks study also has a calibrated modal split model which could be used for this analysis. All have commodity flow predictions for the time frame of interest. The modal split model could thus be applied to the zone-to-zone commodity flows to ascertain what level of change in travel time would divert some specified portion of the truck traffic to rail in selected markets. Links associated with those markets would become prime candidates for further analysis in step 2 (see Section (III.F.2) of the central optimization model.

Another criterion for screening links as high-speed candidates is volume. It is unlikely that lower-volume links would support the investment required to improve them in order to allow high-speed operation, unless substantial diversion could be expected. Speed has greatest impact on high-volume links, and consequently such links are the most likely candidates for upgrading. Under section 503 of the "Rail Act", the FRA [18] has classified track into several categories. Those carrying the highest volume (over 20 million gross tons per year) are called "A-Mainline". Other considerations used in designating track as A-Mainline include: serving a significant market, and meeting national defense needs for an interconnected network. It is likely that the A-Mainline track system will provide a basis on which further screening can be done, since track outside this category would be unlikely to support upgrading.

Still other procedures to be used in screening include identification of corridors of service and high volume O-D pairs. These may lead to choices of likely candidate links, and will certainly be useful for post-optimization analysis and for decisions on likely project implementations. Geographical partitioning to facilitate detailed examination of portions of network may also be useful in screening.

A final criterion for network link screening is an analysis of cost benefit ratios and differences in order to identify links for which the return on the investment is at an acceptable level. (This will be discussed in greater detail in Section F.2.b.) This procedure rests in part on the shaky basis of poor cost estimates, but may provide at least a ranking or general classification of link candidates for use in the later optimization model.

The primary purpose of all these screening operations is to narrow down the candidates for high-speed upgrading, both to facilitate easier handling of network and optimization models in the computer, and also to reduce the number of links for which cost data are critical to a level that may allow reference to additional sources for that data.

Section F. Central Optimization Model

F.1 Step 1

Step I involves modal choice and link assignment to obtain link volumes by commodity class from commodity-flow prediction input. As seen from the flowchart in Figure III-D.1 (page 31), the commodity-flow prediction process is not inside the loop of alternating steps 1 and 2. It is an initialization which needs to be performed only once to provide input to the subsequent analyses. The total flow values (by all modes) do not depend on the link improvements. Since we do not consider the additional transportation demand induced by rail improvement, but only changes in distribution among modes, the flow predictions do not vary.

Path computations, which are part of the assignment model, have two purposes. They provide travel-time input for modal split computations, and also paths to be used in assignment. Capacity impacts may be included for both time calculations and assignment paths by including a volume-dependent factor in the travel time estimation, as is done in the FRA assignment model.

The modal split model chosen for use in this project must be sensitive to travel time, which means that the time elasticity of rail market share must be sufficiently large to reflect the expected time differences. Figures III-F.1 & 2 and Tables III-F.1 & 2 show the results of using the modal split model contained in the National Network Study [42] to analyze market share and revenue changes resulting from reductions in travel time. Although the market share changes are nominal for even quite large time changes, percent revenue changes are fairly large for even small time changes.

Figure III-F-1

ELASTICITY OF RAIL MARKET SHARE WITH RESPECT TO DOOR-TO-DOOR RAIL TIME - MANUFACTURED GOODS

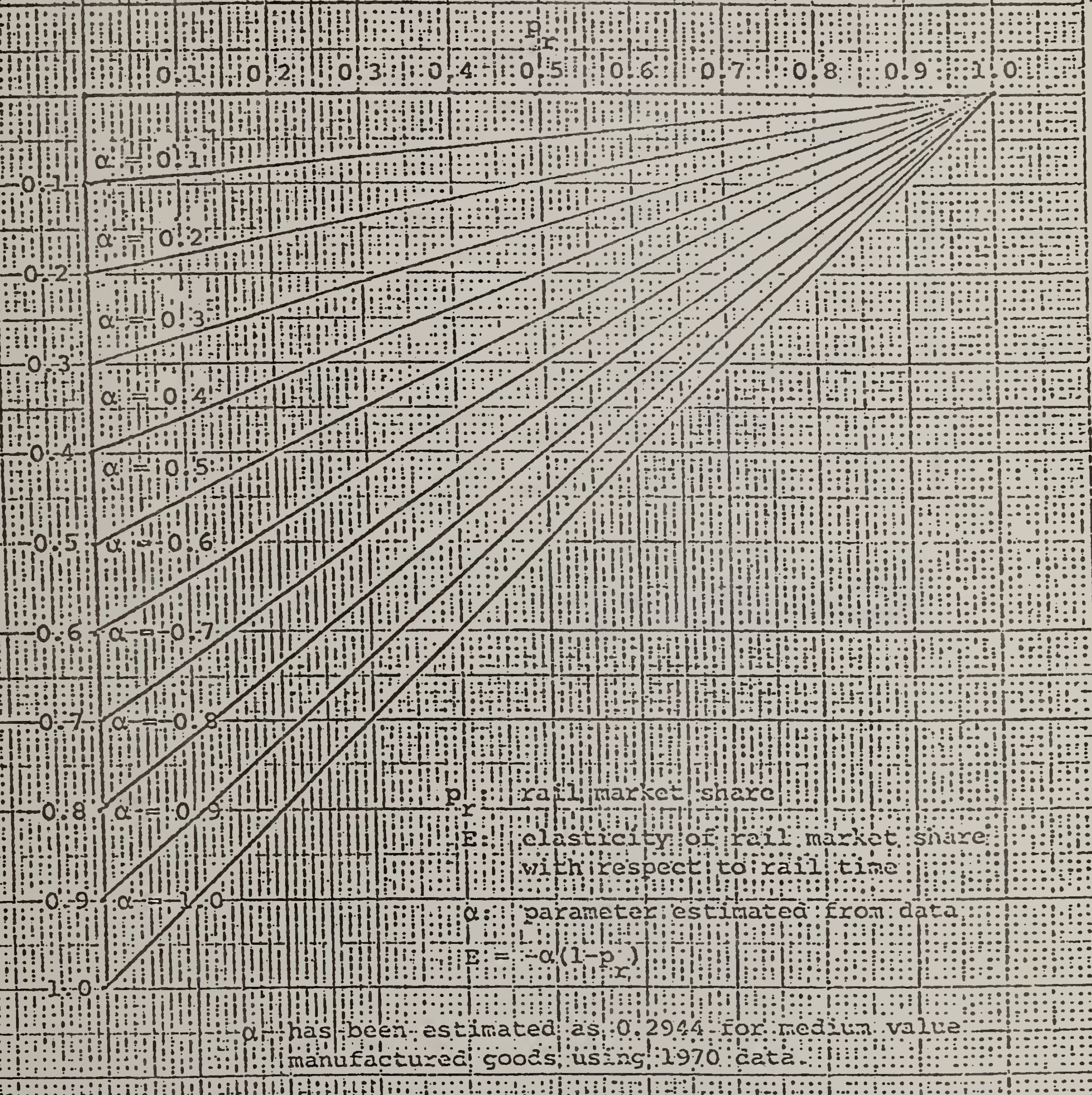


Table III.F.1

RAIL SHARES AFTER DOOR-TO-DOOR TRAVEL TIME REDUCTIONS:

MANUFACTURED GOODS*

Rail % of Market Before Change	Rail Share After Change								
	% Decrease In Rail Time								
	10	20	30	40	50	60	70	80	90
10	.103	.106	.110	.115	.120	.128	.137	.153	.182
20	.205	.211	.218	.226	.235	.248	.264	.288	.333
30	.307	.314	.323	.333	.345	.361	.381	.410	.461
40	.408	.416	.426	.437	.451	.467	.489	.519	.571
50	.508	.517	.527	.538	.552	.568	.589	.618	.666
60	.608	.616	.625	.637	.649	.664	.683	.709	.750
70	.707	.713	.722	.731	.742	.754	.770	.791	.823
80	.805	.811	.816	.823	.831	.840	.852	.866	.889
90	.903	.906	.909	.913	.917	.922	.928	.936	.947
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

*Based on a time elasticity of $E = -0.3(1-p_r)$, where p_r is the rail share for a given O-D pair.

Table III.F.2

PERCENT INCREASE IN RAIL REVENUE DUE TO

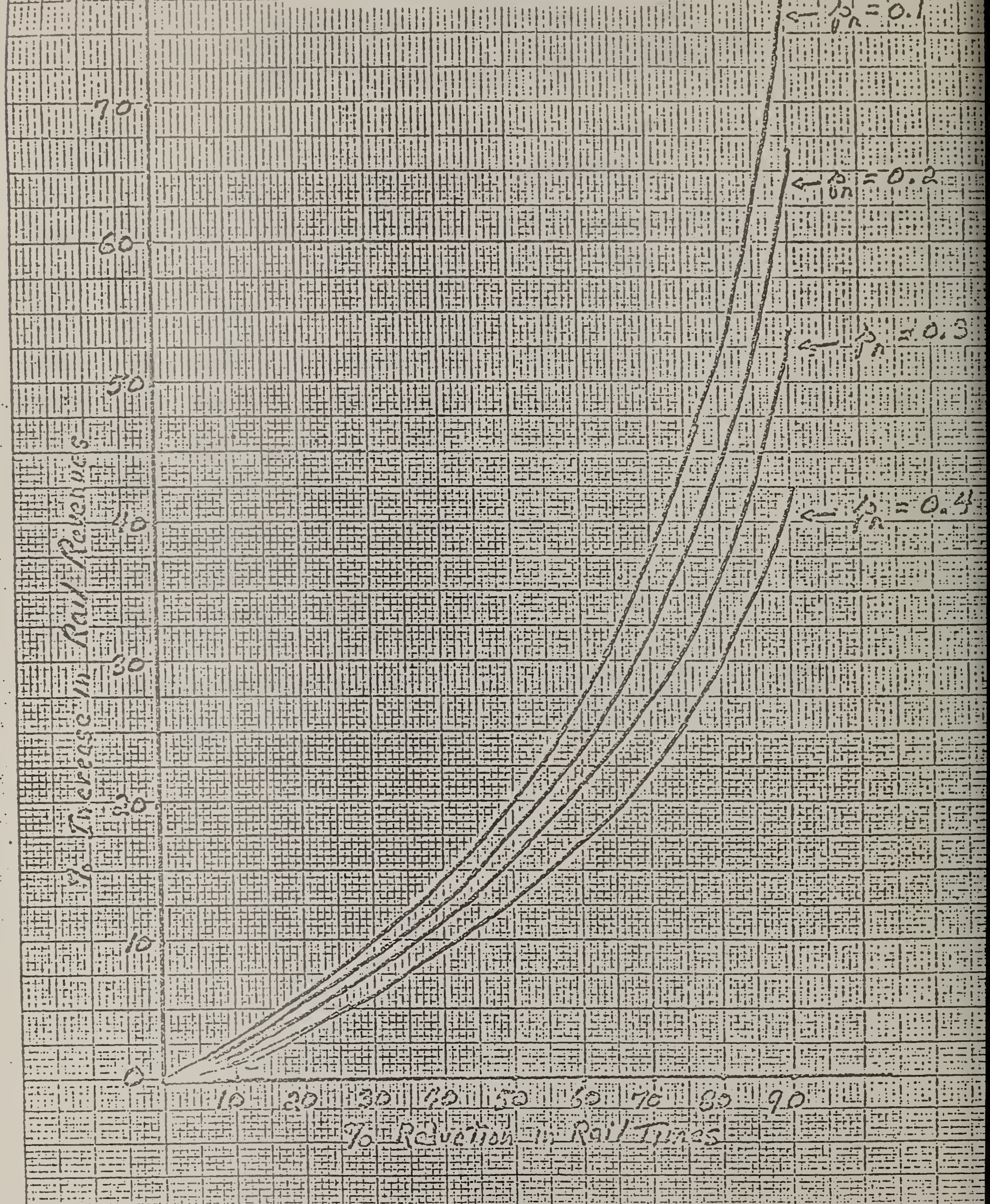
DECREASE IN RAIL DOOR-TO-DOOR TRAVEL TIME*

Rail % of Market Before Change	% Decrease in Rail Door-To-Door Time								
	10	20	30	40	50	60	70	80	90
10	2.87	6.21	10.00	14.65	20.37	27.55	37.49	52.60	81.52
20	2.54	5.49	8.79	12.82	17.70	23.76	32.00	44.18	66.44
30	2.22	4.77	7.61	11.04	15.15	20.19	26.92	36.63	53.68
40	1.90	4.06	6.45	9.31	12.71	16.82	22.22	29.84	42.73
50	1.57	3.36	5.32	7.64	10.38	13.64	17.86	23.69	33.24
60	1.26	2.67	4.21	6.02	8.13	10.62	13.79	18.09	24.94
70	0.94	1.99	3.12	4.45	5.98	7.76	10.00	12.98	17.61
80	0.62	1.32	2.06	2.92	3.91	5.04	6.45	8.30	11.09
90	0.31	0.65	1.02	1.44	1.92	2.46	3.12	3.98	5.25

*Based on a time elasticity of $E = -0.3(1-p_r)$, where p_r is the rail share for a given O-D pair.

Figure III.F.2

Increase in Rail Revenues With Decrease in Rail Times



Small percentage changes in revenues received can represent great increases in the actual amount of revenue. The tables and figures refer to the revenue received for one O-D pair. This must be allocated to appropriate links and the link revenues summed over all O-D pairs between which rail movements use a particular link. However, if percentages from other pairs are similar, the percentage increase in revenue for a link should be similar to that in Table III.F.2.

Once the rail share of an O-D volume has been identified,it must be associated with the links over which it travels. This is known to be difficult, since many rail shipments do not follow the shortest distance path or shortest time path, but rather follow a path determined by train schedules, historical precedent and shipper instructions. There seems to be no one consistent choice function with which path decisions are made. FRA has an operating assignment process which can use a variety of parameters and combinations of them to assign link loadings. As a start the FRA travel time criterion with a correction factor for capacity-caused delays will be used. This involves iterating the assignment model to make the delay incurred consistent with link volume. It is desirable that the link assignment criterion used be sensitive to changes in travel times. Otherwise loading will not be affected by high-speed improvements, an unrealistic situation which would lead to under-representing revenues accrued from the increase in speed.

It will be necessary to devise a procedure for associating commodity flow data, which may be given at a fairly gross level (180 or 500 zones for example), to appropriate network load points. Once an initial loading has been made, it may be possible to assign volumes only to a subnetwork of main-line links, since changes will occur only on a portion of the network and access to that network will not be affected. This would somewhat reduce the size of subsequent assignment steps, but may not be easily accomplished. The most feasible process may be a complete network assignment at each iteration of step 1, even though this will be expensive and require a large amount of computer-time.

F.2 Step 2

Step 2 involves choosing which links to upgrade to high-speed capability. As noted above, different applications of the central optimization model will use several different models to reflect different choice criteria, the three major of which are:

1. Minimize the cost of upgrading to provide a specified level of high-speed service,
2. Maximize service provided subject to a budget constraint,
3. Maximize revenues from diversion.

Using the first of these criteria requires specifying the markets for which provision of high-speed service is desired. The identification of these potential markets (or corridors) for high-speed service is part of the analysis in the initial screening and forms a basis for the definition of several scenarios. For the second criterion, scenarios are specified by the various budget levels to be considered. One method of defining them is to postulate several system sizes, measured by the number of miles to be upgraded, and to multiply those values by an average per-mile upgrading cost. Maximization of diversion involves the choice of markets which offer a potential for rail to capture a share of truck shipments. Choosing links to improve travel times for those markets is similar to the process used for criterion 1, except it is not necessary that each market be served by a path entirely consisting of high-speed links. Choosing appropriate "upgrading corridors", with impacts on markets of potential diversion, is an important step in the initial screening and essentially a manual operation.

The formulations which correspond to criteria 1 and 2 both result in mathematical programming models whose size is determined by how well the screening process is able to reduce the set of links to be considered as high-speed candidates. This is accomplished either (i) by identifying markets to be served by high-speed rail or (ii) by identifying specific links or link sets for which high-speed upgrading will produce large benefits or (iii) by identifying specific links or link sets in which high-speed upgrading will have little effect. The two model approaches will be discussed below.

F.2.a Minimizing Upgrading Costs for Specified Level of Upgrading

The underlying concept of this model is that of achieving a given quality of service at minimum cost. This quality of service is to be attained between each of a set of O-D pairs stipulated by the user of the model for a given "run", and different sets can be used in different scenarios.

The stark version of the model, to be described now, operates with simple dichotomies. A link either is, or is not, of high-speed quality. An O-D pair either enjoys high-speed quality of service, evidenced by its being connected by at least one path of high-speed links, or else it does not. There is an "adequate capacity" assumption; this implies that high speed traffic does not interfere with either traffic on unimproved links or high speed traffic of other O-D pairs. This should be checked, in the context of the high-speed network produced by the model.

To start the formalities, let N and L denote the node-set and link-set of the rail network. With each link $\lambda \in L$ is associated a binary decision variable

$$x(\lambda) = \begin{cases} 1 & \text{if } \lambda \text{ is brought to or already is high-speed status} \\ 0 & \text{otherwise,} \end{cases}$$

and a positive problem datum (assumed given)

$c(\lambda)$ = cost of bringing λ from present condition to high-speed status.

Thus the objective is to

$$\text{minimize } \Sigma\{c(\lambda)\ x(\lambda):\ \lambda \in L\}\ . \tag{2.1}$$

In order to describe the constraints, other than

$$x(\lambda) \in \{0, 1\}\ , \tag{2.2}$$

let (O_k, D_k) denote the k-th of the K stipulated O-D pairs. In words, the model constraint associated with the k-th pair is that this pair be joined by at least one path consisting entirely of links that have been brought to high-speed status.

There are at least two different ways to formulate this condition algebraically. For the first of these, let

$$P_k = \text{the collection of paths } p \text{ joining } (O_k, D_k), \tag{2.3}$$

and let

$$\delta(\lambda,p) = \begin{cases} 1 & \text{if link } \lambda \text{ lies on path } p, \\ 0 & \text{otherwise.} \end{cases}$$

Introduce variables

$$y(p) \in \{0, 1\}$$

constrained by

$$|p|y(p) \leq \Sigma\{\delta(\lambda,p)\ x(\lambda): \ \lambda \in L\} \tag{2.4}$$

where $|p| = \Sigma\{\delta(\lambda,p): \ \lambda \in L\}$ denotes the number of links in p. Since $\Sigma\{\delta(\lambda,p)\ x(p): \ \lambda \in L\}$ is the number of links of p which are of high-speed quality, it follows that $y(p) = 0$ unless p has been made a high-speed path. Finally, form the constraints

$$\Sigma\{y(p): \ p \in P_k\} \geq 1 \qquad \text{for } 1 \leq k \leq K. \tag{2.5}$$

For the second formulation, consider a fictitious commodity C_k called "high-speed travel" which is to be moved from O_k to D_k. A link λ has "capacity" 1 or 0, to accomodate high-speed travel, according as it has been brought to high-speed status or not. The desired high-speed path from O_k to D_k exists if and only if at least one unit of C_k can flow from O_k to D_k without violating these capacity conditions. Introduce flow variables

$$f_k(\lambda) = \text{flow of } C_k \text{ on link } \lambda\ , \ f_k(\lambda) \in \{0,1\}$$

Ignoring for the moment the fact that links are undirected, we formulate the conservation conditions

$$\Sigma\{f_k(i,j):\ (i,j) \in L\} - \Sigma\{f_k(j,i):\ (j,i) \in L\} = 0 \qquad (2.6)$$

$$\text{for all } i \in N - \{O_k, D_k\} \text{ and all } k\ ,$$

the conditions assuring connectivity

$$\Sigma\{f_k(O_k,j):\ (O_k,j) \in L\} - \Sigma\{f_k(j, O_k):\ (j, O_k) \in L\} = 1, \quad (2.7)$$

$$\Sigma\{f_k(j, D_k):\ (j, D_k) \in L\} - \Sigma\{f_k(D_k, j):\ (D_k, j) \in L\} = 1, \quad (2.8)$$

and the capacity conditions

$$0 \leq f_k(\lambda) \leq x(\lambda)\ . \qquad (2.9)$$

Either formulation gives rise to a large integer linear problem that one would not (sanely) attempt to set-up and solve explicitly by general-purpose methods. The question is whether adequate "tailored" special-purpose algorithms, exact or approximate, can be found.

We now consider some complications. They fall under two main headings: noncircuity, and multichotomy.

The point of the first heading is that the stark model may leave some O-D pairs joined by one or more high-speed paths, but all of them very long or circuitous. This would not truly realize the level of service concept intended by the model.

There are several approaches that might be tried to guard against this danger. In connection with (2.3), P_k might be limited to relatively non circuitous paths. In (2.6 - 2.9), when dealing with the k-th O-D pair one could restrict attention to links located and oriented so as to be reasonable possibilities for fairly direct movement from O_k to D_k. Identifying such links (and orientations) could be carried out using the node-labels from a preliminary calculation which, for each k, used a label-setting algorithm to build a shortest-path spanning tree rooted at O_k. (Some duplication can be avoided if several O-D pairs have the same origin, as seems likely.) For (2.6 - 2.9) it would be necessary to replace each (undirected) link by a corresponding pair of oppositely directed arcs, but for most links and each k, one of the two orientations will in fact be unreasonable for "O_k to D_k" movement and can therefore be omitted.

Under the heading of "multichotomy", we observe that our notion of a link as high-speed or not, and the corresponding definition of high-speed connection of an O-D pair, may well be unacceptably oversimplified. The simple cost coefficients $c(\lambda)$ might need to be replaced by functions

$c(\lambda,t)$ = cost of upgrading link λ to reduce its traversal time to t,

and the simple binary variables $x(\lambda)$ by variables

$t(\lambda)$ = traversal time for link λ.

Then (2.1) would be replaced by

$$\text{minimize} \quad \Sigma\{c(\lambda,t(\lambda)) : \lambda \in L\} . \tag{3.1}$$

The "level of service" specification would include a stipulated value for

τ_k = maximum required traverse time, O_k to D_k.

Then P_k in (2.3) would be restricted to consist of paths p, from O_k to D_k, for which

$$\Sigma\{\delta(\lambda,p)t(\lambda): \lambda \in L\} \leq \tau_k , \tag{3.2}$$

so that the sets P_k depend on the $t(\lambda)$'s. A full algebraic formulation corresponding to (2.3 - 2.5) is not attempted here. For the formulation (2.6 - 2.9), one might try replacing the "1's" of (2.7) and (2.8) with other values related to the τ_k's, and (2.9) by

$$0 \leq f_k(\lambda) \leq t(\lambda) .$$

Possibly the variables $t(\lambda)$ can be usefully discretized to 3-5 levels; then one can replace each link by a bundle of parallel links, each with its own (c,t) values.

F.2.b Maximizing Service for a Given Budget

The initial, admittedly simplistic, model is described below using the following notation:

c_ℓ - cost for improving link ℓ,

v_ℓ - volume of demand over link ℓ,

t_ℓ - improvement in travel time on link ℓ, if it is improved,

B - budget level,

$x_\ell - \begin{cases} 1 \text{ if link } \ell \text{ is improved,} \\ 0 \text{ if link } \ell \text{ is not improved.} \end{cases}$

Then we may state the optimization to be performed as:

Model 1

$$\max \sum_\ell t_\ell v_\ell x_\ell$$

$$\text{subject to:} \quad \sum_\ell c_\ell x_\ell \leq B$$

$$x_\ell \in \{0,1\} \text{ for all } \ell .$$

Examining these conditions shows that Model 1 turns out to be a very special type of linear programming problem, namely, a "knapsack" problem. Such problems have been studied extensively [44] and satisfactory algorithms for their solution are known.

This formulation considers improvement as only a dichotomous variable; either a link is improved or it is not. There are no different levels of improvement or alternative improvements considered for a link. A later model version will consider such factors.

The measure of system benefit, namely, improved service to "current" users, is the product of the link volume, and the time saved; thus ton-hours saved multiplied by speed improvement. Time saved alone would not be sufficient to measure since we need to have time savings weighted by volume, and volume benefit alone is not satisfactory since the time savings depends on the link.

This formulation does not have any contiguity requirement, as does that proposed in the previous section. Therefore it is possible that the optimization might choose not to improve a link that lies between two improved links. It is not clear that this is necessarily undesirable, since it could occur in one of several ways. The middle link may have a significantly lower volume than its neighbors, in which case there is little through-traffic to benefit from a high-speed line. The middle link may not be amenable to much improvement, either because it is already pretty fast or because there are special considerations (grade or other terrain, environmental constraints, bridge structure etc.) which limit possible improvement levels. A third way in which a link between two improved links might not be chosen to be improved is if the cost of improving the middle link was very high compared to that of the other two. For any of these reasons, contiguity of improved trackage may not result naturally from the optimization process. The optimization described here will, however, tell which links are really most cost-effective for improvement. Adding additional constraints on contiguity decreases the return on investment, so that the solution to the above process is in some sense an upper bound on the possible return from a given budget level.

As an initial approximation, in screening candidate links for further study, one might examine the following optimization problem:

Model 2

$$\max \sum_{\ell} x_{\ell}$$

subject to:

$$(at_{\ell}v_{\ell}-c_{\ell})\, x_{\ell} \geq 0, \text{ for all } \ell$$

$$x_{\ell} \in \{0,1\}, \text{ for all } \ell.$$

where we can interpret a as a constant which gives the value of a ton-hour of improvement to the system. The solution of this model is computationally trivial. This in effect picks all links which are profitable, since it seeks to identify those links, which have the property that

$$a t_\ell v_\ell \geq c_\ell .$$

Model 3

A formulation which allows various levels of improvement on each link is a direct generalization of Model 1. Three new variables are:

$t_{\ell i}$ - time saved by improving link ℓ to level i

$c_{\ell i}$ - cost of improving link ℓ to level i.

$x_{\ell i}$ - $\begin{cases} 0 & \text{if link } \ell \text{ is not improved to level i} \\ 1 & \text{if link } \ell \text{ is improved to level i, or is already at or above level i } (c_{\ell i}=0). \end{cases}$

The optimization problem then becomes:

$$\max \sum_\ell \sum_i t_{\ell i} v_\ell x_{\ell i}$$

subject to

$$\sum_\ell \sum_i c_{\ell i} x_{\ell i} \leq B$$

$$\Sigma_i x_{\ell i} \leq 1$$

$$x_{\ell i} \in \{0,1\}$$

Another formulation considers possible multi-link improvement "projects," with likely candidates identified from the outputs of the preceding models. This allows inclusion of contiguity requirements. If a project is implemented, all links affected by that project are improved. The notation to be used in this model formulation includes:

y_p - $\begin{cases} 1 \text{ if project p is implemented} \\ 0 \text{ if project p is not implemented} \end{cases}$

$L(p)$ - the set of links to be improved by project p

Model 4

$$\max \sum_{\ell} t_\ell \, v_\ell \, x_\ell$$

subject to:

$$\sum_{\ell} c_\ell \, x_\ell \leq B$$

$$x_\ell \leq \Sigma\{y_p : \ell \in L(p)\}$$

$$\sum_{\ell \in L(p)} x_\ell \geq |L(p)| \, y_p$$

$$x_\ell, y_p \in \{0,1\}$$

The first constraint is the budget constraint. The second constraint insures that a link is improved only as a part of some project. The third constraint makes sure that if a project is implemented, all links on that project are improved.

Model 3 suffers from the difficulty of having a large number of variables, namely, the product of the number of links and the number of improvement levels of each link. As noted earlier, this may be cut somewhat by initial screening of links to limit the choice to those with potential for cost-effective improvement. Model 4 has many fewer variables, but at the expense of requiring a designation of appropriate projects. These could be single-link improvements, in which case the model reduces to Model 1. Projects could also include contiguity requirements, since one project may involve improving several links which are only improved if all are improved.

Improvements could include yard improvements if yard impedences are represented directly on network links. Projects encompassing yard upgrading could thus be included in Model 4. The initial screening should address the question of whether it is possible by any level of improvement on rail links alone to have a measurable impact on rail revenues. Various yard improvement levels should also be considered, to identify those with greatest potential for inclusion in the subsequent analysis in the central model.

The model described in Section F.2.a seeks to minimize cost subject to a constraint that certain areas (O-D corridors) must have high-speed service; the models described in this section seek to maximize service for a given investment budget. Both are oriented toward the "current" rail traffic. Since Step 1 includes a time-sensitive modal split modal generating the "current" traffic for the next pass through Step 2, there will be some diversion from other modes within the alternating two-step iterative approach. However, the model of the previous section can be applied specifically to those O-D pairs which offer greatest potential for diversion.

An alternate approach in choosing links to improve might be to choose those links which give the greatest diversion from other modes (primarily truck). This approach could be used in initial screening to determine those links and markets for which improvement of a link or set of links would divert some threshold level of traffic from competing modes. Such an analysis would ignore budget constraints, and simply investigate the possibility that substantial traffic from other modes can be diverted by <u>any</u> high-speed improvements of the type being considered. If there is potentially divertable traffic, then the approach would identify which projects would lead to diversion, making them desirable candidates for further analysis. Diversion of traffic could be included explicitly in the objective functions of Models 1, 3 and 4, either as an additional summand or as an alternative to time-savings, provided that capture of a larger modal share is accepted as a major objective of high-speed rail improvement.

F.3 Link Improvement Rankings

The output of the centeal optimization model consists of a set of links for each of the model runs, each run representing a different scenario. It will be necessary, in responding to the requirements of Section 901-(6) of the Rail Act, to provide a composite ranking of the links according to their potentials for high-speed improvement. One method of achieving such a link ranking is to rate the scenarios according to their likelihood and to give that rating to each of the links output from the run of that scenario; other links receive a rating of zero for the scenario. The final rating for each link is the sum of its ratings for each individual run, and links are then ranked on their ratings. This process would result in many links receiving a rating of zero, since it is expected that many links will never be chosen for high-speed improvement.

In addition to ranking links, it is also necessary to investigate reasonable high-speed improvement projects. Since a composite ranking scheme is likely to intersperse links from different geographical areas, some method of aggregating the individual link outputs into high-speed corridors or other projects of improved link aggregates must be devised. A major part of such an analysis is the identification of contiguous or nearly contiguous sets of high-ranking links. One possible method to obtain these is to start with the highest-rank link. Include it in the first high speed aggregate subnetwork, and then attempt to extend that network by appending any contiguous link with an acceptably high ranking. Continue in this way until no more links can be added. Perform a similar network "growing" process starting with the highest ranking link not in the first subnetwork. Keep up this process until all links of acceptably high rating have been included in some subnetwork.

After link aggregates have been identified, it is necessary to establish some scheme for rating them. This might be accomplished using some function of the individual link ratings as the composite rating for the aggregate. Another approach is to rank projects on the basis of potential revenues or some other benefit measure. Some consideration must be given to the staging of the projects; whether to start implementing several at once perhaps (proceeding on each from the most profitable link out to less profitable ones), or alternatively, to proceed one project at a time implementing them in order of total return.

We emphasize that the procedures described in this document operate at a fairly gross level of description of individual link characteristics. When major projects have been identified by this process, it will still be necessary to investigate further the practicality of the link choices and of the appropriate detailed improvements to achieve high-speed capabilities. Many factors that were specifically excluded in the more macro-level of analysis described here must be considered at that point. Physical link characteristics, such as grade, curvature, and bridge structures, will affect the required improvements and the costs of those improvements. Operational factors such as siding lengths, train sizes, train schedules, and passenger operations must also be considered. Managerial decisions and approaches can also have a great effect on the effectiveness of high-speed improvements. Political factors will undoubtedly enter the debate and should at least be anticipated. Some reconciliation of the high-speed links proposed in this process with the improvements or decisions made under other sections of the Rail Act must be performed to ensure consistency of DOT recommendations to Congress. In particular, it is likely that many of the factors that will influence the choice of links to improve to high-speed status will also characterize candidates for electrification. Coordination of the outputs from these two sections with studies implementing other parts of the Rail Act is critical. Coordination with others working on the Act will also be required to assure the latest values of input parameters such as the current track condition data and the yard operation parameters.

Project output will also identify improvements in rail properties advantageous to the expeditious movement of passenger traffic. It is impractical to combine the optimization of the two types of movement, passengers and freight, because of the difficulties of constructing composite measures of benefits and costs which include both types of traffic. Passenger link improvements must also be coordinated with other recommendations of DOT.

In addition to link and project rankings, output from this work will include tabulation of costs and benefits associated with the various improvements. The benefits (described earlier) associated with environmental, energy, safety, and passenger traffic will be quantified and identified with specific projects where possible. Costs will also be displayed on a link-by-link and project-by-project level, although it is again noted that these are not detailed costs based on careful engineering analyses of link characteristics.

Section G: <u>Rail Passenger Service</u>

From the early days of railroading, passenger and freight trains have operated jointly over a common track network. One recent study [45] suggests that this joint use can safely continue as passenger train speeds increase, provided suitable control systems are installed which maintain time and space separations and provide rapid notice to moving trains of potentially hazardous situations. Although the future of rail transportation depends primarily on the efficient movement of freight, the expectation that passenger and freight service can safely share common track networks suggests that the most attractive potential passenger-routes should be explored for possible speed improvement. A means for identifying routes is presented in this section.

In late 1971, as part of the National Network Simulation Project, the National Bureau of Standards identified eleven travel corridors where estimated patronage indicated that passenger service could be provided at reasonable cost. In alphabetical order, these corridors were:

Boston--Washington

Buffalo--Syracuse--Albany--New York City

Chicago--Cincinnati

Chicago--Cleveland

Chicago--Minneapolis

Chicago--St. Louis

Cincinnati--Cleveland

Cincinnati--Detroit

Los Angeles--San Diego

Philadelphia--Pittsburgh

Portland--Seattle

In these corridors, passenger service could be provided at a cost per passenger mile of ten cents. When cost per passenger mile was plotted for each corridor in increasing order, there was a sharp rise in cost per passenger mile after ten cents per mile. This breakpoint phenomenon persists when the curve is shifted upward by replacing 1971 costs with 1977 costs.

The freight-oriented analysis described earlier should be supplemented by examining the effects on passenger-train patronage of increasing speeds stepwise in these corridors from the 1972 speeds of 110 miles per hour. As passenger-train speeds are increased, corridor travelers will increasingly divert to the rail mode. Priorities for improving rail passenger train trackage will be established by relating the costs of the improvements (including terminal improvements) to corridor benefits achieved on a regional basis. Such benefits would include reduced fossil-fuel consumption, reduced air and noise pollution, lessened congestion for highway and short-range air traffic, and reduced need for additional highway lanes and air-terminal capacity.

The basic approach to estimating the effects of increased rail speeds on passenger trains is identical to that used in the freight analysis. The essential differences lie in the demand projection and modal choice models. Again the concern is primarily with the increases in rail volumes due to the diversion from other modes, and not with the additional demand for travel that may be induced by the overall improvement in the transportation system.

There are a number of intercity modal choice models available Seven such models developed for the Northeast Corridor Transportation Project have been tested on non-corridor data [46]. Model CN27 was determined to be the best of those models on Northeast Corridor data; and for non corridor data the authors assert "Model CN27 provides the least amount of variability between observed and estimated rail volumes...". An alternative to CN27 is CN22, which does not require that passenger traffic be divided by purpose. Still another possibility is the modal choice model developed for the National Network Simulation project. This model was calculated on a national data base and suggests somewhat lower travel time-elasticities than do the Northeast Corridor models. The rail travel time exponents in the Northeast Corridor models varied between -1.5 and -3.38, while the national-level models have exponents greater than -1.0. Tables G-1 and G-2 illustrate the impacts of travel-time reduction for a time exponent of -0.75.

The impacts of passenger train travel time reductions (speed increases) will be explored in each of the major corridors and will be tabulated subordered to freight listings.

Table G-1

RAIL SHARES AFTER DOOR-TO-DOOR TRAVEL TIME

REDUCTIONS: PASSENGER SERVICE*

Rail share before travel time change %	Travel Time Change (percent) 10	20	30	40	50	60	70	80	90
10	.107	.116	.127	.140	.157	.181	.215	.271	.385
20	.213	.228	.246	.269	.296	.332	.381	.455	.584
30	.317	.336	.359	.386	.419	.460	.514	.589	.707
40	.419	.441	.467	.494	.529	.570	.622	.690	.789
50	.520	.542	.567	.595	.627	.665	.712	.770	.849
60	.619	.639	.662	.688	.716	.749	.787	.834	.894
70	.716	.734	.753	.774	.797	.823	.852	.886	.929
80	.812	.825	.839	.854	.871	.888	.908	.930	.957
90	.907	.914	.922	.930	.938	.947	.957	.968	.981

*Based upon time exponent of -0.75.

Table G-2

PERCENT INCREASE IN RAIL PASSENGER REVENUE DUE TO

DECREASE IN RAIL DOOR-TO-DOOR TRAVEL TIME*

Rail fraction of market before travel time change %	Travel Time Change (percent) 10	20	30	40	50	60	70	80	90
10	7.34	16.10	26.78	40.14	57.44	80.94	115.14	170.88	284.55
20	6.47	14.06	23.12	34.16	48.00	66.01	90.73	127.66	192.17
30	5.62	12.09	19.66	28.66	39.62	53.36	71.31	96.33	135.58
40	4.78	10.19	16.39	23.60	32.14	42.49	55.47	72.58	97.36
50	3.95	8.35	13.30	18.93	25.42	33.07	42.31	53.96	69.80
60	3.13	6.57	10.36	14.59	19.35	24.81	31.21	38.96	49.00
70	2.33	4.85	7.57	10.56	13.85	17.52	21.71	26.63	32.74
80	1.54	3.18	4.93	6.80	8.82	11.04	13.50	16.30	19.68
90	0.77	1.57	2.40	3.29	4.23	5.23	6.32	7.54	8.96

*Based upon time exponent of -0.75.

IV. A SIMPLIFIED APPROACH

We outline here an alternate approach to evaluation of high-speed projects. It is simpler in form and more straightforward to implement, amd, although it does not capture some subtleties of the prior approach, it can be to compare user-supplied potential projects. The approach emphasizes financial viability of the projects. The steps are:

1. Use the Transportation System Center (TSC) demand projections, by by commodity class, which are available on tape for the forecast year. These are from Bureau of Economic Analysis (BEA) area to BEA area and must be allocated to the National Network System (NNS) zone system using the NBS program [43].

2. Estimate rail shares using the NNS modal split model.

3. Assign O-D flows to rail network using FRA network model to produce link loadings.

4. Using tariff estimating equations , convert link loadings to link revenues: R_{ℓ}^{0} . The superscript indicates the current scenario (0 representing no changes in the system), and the subscript indicates the link.

5. Specify an upgrading scenario S and introduce resulting link speeds. Changes in yard times may also be introduced here.

6. Use the FRA network model to estimate new zone-to-zone rail times.

7. Calculate $\Delta T_{ij}^{S} = T_{ij}^{S} - T_{ij}^{0}$, the change in rail shipment time between regions i and j.

8. Estimate rail shares based on new rail shipment times.

9. Assign resulting volumes to rail network to obtain link loadings.

10. Convert the link loadings to link revenues: R_{ℓ}^{S} .

11. Calculate $\Delta R_{\ell}^{S} = R_{\ell}^{S} - R_{\ell}^{0}$, the change in revenue due to scenario S, for each link.

12. Estimate link benefits based on ΔR_{ℓ}^{S}, ΔT_{ij}^{S}.

13. Use the TSC cost model to estimate link operating and maintenance costs: M_{ℓ}^{S}.

14. Combine with annualized capital improvement costs I_{ℓ}^{S} to obtain total costs:

$$C_{\ell}^{S} = I_{\ell}^{S} + M_{\ell}^{S} .$$

15. Categorize the link improvements in scenario S according to chosen benefit-cost criterion.

Wide latitude is left in the choice of scenarios in step 5. This allows great flexibility, and is the major difference between this approach and that of section III. No optimization is employed here, providing assurance that this approach can be carried out quickly. However, optimal choice of scenarios is not guaranteed. (It may be that a link improvement with low cost-benefit measure is necessary to obtain high benefits from some other improvement.)

V. WORK PLAN

To implement the concepts developed in the preceding chapters, the following tasks should be performed to meet the requirements of Section 901(6) of the Rail Act. These tasks have been detailed in the previous text. We have been careful not to obscure the fact that one important decision--selecting the "least unsatisfactory" method for estimating link upgrading costs--remains to be settled during the study itself.

1. Coordinate with groups working on other relevant rail studies (e.g. electrification, yards and terminals, deferred maintenance).
2. Obtain and assimilate specific models to be used.
3. Examine and assimilate data sources.
4. Select (or construct if necessary) submodels required for treating:
    a. yard impedances
    b. terminal impedances
    c. tariff/revenue relations
    d. commodity-flow prediction (all-modes total)
    e. passenger-flow prediction (all-modes total)
5. Estimate costs:
    a. select model (probably TSC's) for estimating maintenance and operating costs
    b. examine alternative procedures for estimating capital costs of upgrading:
        i. FRA link model (speeds)
        ii. extension of Dyer approach (deferred maintenance)
        iii. Texas A&M data base (timetables)

iv. possible estimation from freight volume and financial status of owning railroad.

6. Set up procedure to quantify benefits within the model context:
   a. revenues
   b. opportunity costs of time saved
   c. societal benefits
7. Perform initial screening based on:
   a. markets with potential division
   b. revenue potential
   c. costs and benefits
8. Exercise evaluation approach of Section V:
   a. choose scenarios (with FRA)
   b. exercise procedures
   c. interim report
9. Select parameter settings (budget levels, yard impedances, etc.) and adapt algorithms for optimization.
10. Apply central optimization model:
    a. initialization (commodity-flow projections) from Task 8
    b. step 1
       i. modal split
       ii. link assignment
    c. step 2
       i. choose links for upgrading
       ii. check convergence; iterate if necessary
11. Develop and apply procedures for analyzing and aggregating model outputs:
    a. link ranking
    b. project selection and staging
    c. tabulate costs and benefits

12. Prepare final report

The timing for accomplishing these tasks is displayed in the acompanying work schedule. We list below our anticipations for the various efforts (in personnel-days) to be expended on the 12 tasks.

Tasks	Personnel-days
1. Coordination	5
2. Assimilation of models	15
3. Assimilation of data	10
4. Submodel selection	15
5. Cost estimation	30
6. Benefit quantification	5
7. Initial screening	50
8. Exercise of simplified approach	40
9. Parameter setting	10
10. Model application	60
11. Output analysis	40
12. Documentation	40
Total	320

The preceding estimates and work schedule are based on the assumption that only 12 weeks will be available for completion of the study. This time limitation will impose severe pressures on the analysis. We urge that, if possible, a larger period be sought so as to permit a more complete and definitive treatment of this complex problem area, to allow for possible delays in receipt of ostensibly available data, and to allow for problems with ostensibly "ready-to-go" software. The availability of interim "outputs" from Task 8 may make such an extension more palatable.

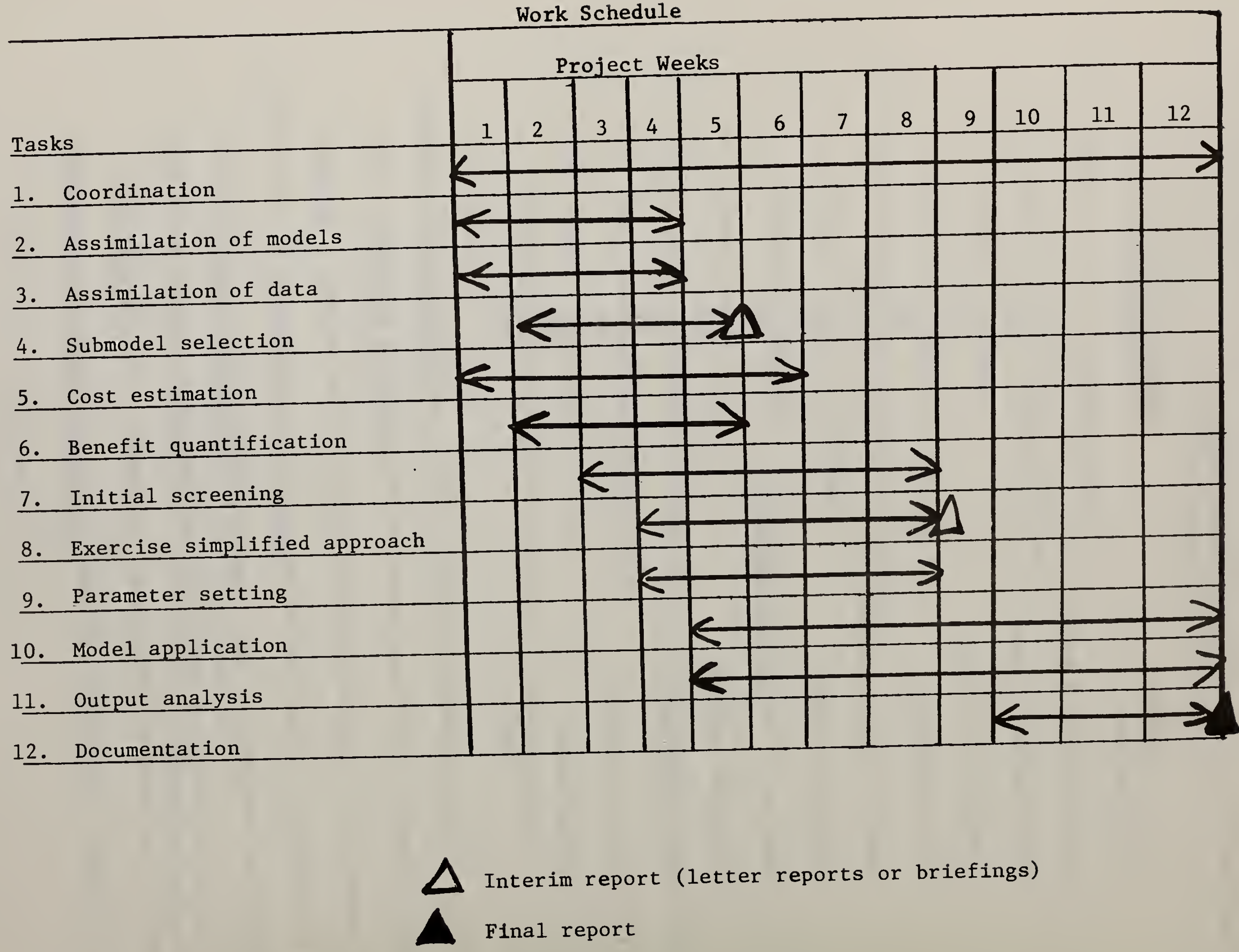


Figure V-1 Work Schedule

To provide a "ballpark" idea of the cost for executing this study plan, we have estimated its cost if performed by our own group:

Category	$(in thousands)
personnel*(230 days)	62.1
consultants*(90 days)	27
travel	3
computer**	13
total	105.1

*Personnel costs for in-house staff are calculated at an average of $270 per day, reflecting availability of summer workers from universities if study is performed during June-August 1977. Consultant costs are estimated at $300 per day.

**The computer-cost estimate does not include application of the FRA assignment model, which is assumed to be done under FRA auspices.

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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.)*

Section 901-(6) of the Railroad Revitalization and Regulatory Reform Act of 1976 (PL 94-210) calls for a listing and prioritization of rail properties to be improved to permit high-speed operations. This report identifies key factors entering the choice of links for such upgrading, and formulates an analytical methodology (and implementation plan) to support the decision process.

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)*

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