METHODOLOGY FOR EVALUATING THE COST AND BENEFIT OF ADVANCED BRAKING AND COUPLING SYSTEMS

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Final Report

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The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.
This report presents a quantitative methodology for evaluating the costs and benefits of advanced railroad braking and coupling systems. Starting with a specification of the performance characteristics of candidate systems, the methodology employs four major elements to enable the user to compute financial impact and identify institutional changes required. The *operations* element is used to evaluate required manpower and operational changes and to estimate incremental costs for road and yard operations. The *dynamics* element deals primarily with accident and maintenance costs. Under the category of *equipment*, new maintenance procedures are identified and incremental equipment costs are estimated. Finally, the *financial and institutional* element is used to determine the likely results of developing and introducing advanced systems.

This methodology is being utilized to evaluate the costs and benefit of nineteen candidate systems. Results of such evaluation will be presented in the final report of this contract.
### METRIC CONVERSION FACTORS

#### Approximate Conversions to Metric Measures

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1°F = 0.56°C (exactly). For other exact conversions and more detailed tables, see NBS Circular 276, Units of Weight and Measures, Price 22.23, SD Catalog No. C13.10-276.

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#### Approximate Conversions from Metric Measures

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<td>°C</td>
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This report is part of a larger study to identify potentially cost-effective advanced braking and coupling systems and to prepare a plan for conducting the research and development needed to bring about implementation of these systems. It presents the techniques used to evaluate the costs and benefits of developing and implementing these systems.

The authors express their appreciation to the people and organizations that have helped considerably throughout this project. The FRA COTR's, Mrs. Marilynne Jacobs and subsequently Dr. N. Thomas Tsai, have provided invaluable guidance and direction. In addition, an industry committee composed of Messrs. Geoffrey Cope of Dresser Industries, John Punwani of the Association of American Railroads, Bruce Shute of the New York Air Brake Co., Donald Whitney of the Burlington Northern Railroad and Carl Wright of Westinghouse Air Brake Co. have performed important review and consultation. The American railroad industry, in particular the Southern Railway, Boston and Maine, and several other railroads, has graciously provided information and an opportunity to observe railroad operations.
EXECUTIVE SUMMARY

An overview of the methodology to evaluate the costs and benefits of developing and implementing advanced braking and coupling systems is shown in Figure E.1. The evaluation of candidate systems and components starts with the development of performance specifications, as shown in the oval on the left. These specifications are then used to evaluate the corresponding systems for operations, dynamics, and equipment. The resulting manpower and operational changes, incremental costs, and new maintenance procedures are then used in financial and institutional analyses to determine the two major outputs of the study: financial impact and necessary institutional changes.

Table E.1 lists the systems and components that will ultimately be specified and subsequently analyzed, and it groups these systems according to major areas of benefit and whether or not they are primarily mechanical or electrical. (Systems are identified in this report to ensure that the methodology is adequate for their evaluation; they will be evaluated and discussed in a companion report to be prepared later.)

![Figure E.1. Overview of Methodology.](image-url)

<table>
<thead>
<tr>
<th>Area of Improvement</th>
<th>Operations</th>
<th>Dynamics</th>
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<td>• Knuckle-opener&lt;br&gt;• Coupler centering device&lt;br&gt;• Automatic air line connector&lt;br&gt;• Incompatible coupler</td>
<td>• Truck-mounted brakes&lt;br&gt;• Disk brakes&lt;br&gt;• E couplers with shelves&lt;br&gt;• High-strength couplers&lt;br&gt;• Zero-slash couplers</td>
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<tr>
<td>Electrical</td>
<td>• Electrical connector&lt;br&gt;• Locomotive-controlled couplers&lt;br&gt;• Automatic brake bleed&lt;br&gt;• Locomotive-designated car brakes&lt;br&gt;• Ultrasonic brake control&lt;br&gt;• Train condition monitor</td>
<td>• Load sensor&lt;br&gt;• Radio controlled brake link&lt;br&gt;• Electropneumatic brake&lt;br&gt;• Electronic brake</td>
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</table>

![Table E.1. Candidate Systems for Evaluation](image-url)
The yard and road operations component of the methodology relies on models that account for the time and manpower required for each braking and coupling operation in yard handling and local pickup and delivery over the road. The emphasis of these models is on the labor and equipment utilization time and costs that can potentially be saved through faster operations and possibly reduced manpower.

The yard model accounts for the four major operations:

- **Yard train** — an arriving train is delivered to one or more receiving tracks and inspected.
- **Classification** — cars are removed from receiving tracks and sorted onto classification tracks.
- **Pulldown** — cars on classification tracks are trimmed and assembled on departure tracks.
- **Power brake test** — air hoses are coupled, and an outbound test and inspection is performed.

The road model consists of a basic pickup and delivery of cars to a single siding. The locomotive uncouples from the remaining train waiting on the branch or main line, clears the switch, and backs on to the siding to pick up waiting cars. Cars are delivered from near the middle of the train through a similar sequence of maneuvers.

Dynamic effects are evaluated by first estimating intermediate variables, such as train stopping distance, lateral/vertical (L/V) force ratios, and longitudinal in-train forces; and then relating these variables to cost-incurring effects like collisions, derailments, and component failure. Values of train dynamic variables are determined for a baseline system and for candidate advanced systems by executing a train dynamics model for a range of operating scenarios. The model used is the Train Operations Simulator (TOS) developed by the Association of American Railroads (AAR).

The analysis of collision and derailment cost savings related to stopping distances and L/V ratios are based on extrapolations of Federal Railroad Administration (FRA) accident statistics. Baselines are established by including all costs reported to the FRA that apply to accidents that could be mitigated by means of an advanced braking and coupling system. When these costs are adjusted upward to account for nonreportable costs for lading damage and accident clean-up, the baseline becomes approximately $30 million for collisions and $1 million for derailments caused by excessive L/V. The latter cost is sufficiently small to be neglected in further work. A similar assessment of costs resulting from component failure is conducted by first performing a fatigue analysis to relate changes in failure rates to changes in force levels and then extrapolating baseline costs.

Equipment is evaluated by considering existing designs and by developing hardware concepts, where designs do not exist. Existing designs, obtained primarily from patents and the literature, will be costed primarily with the assistance of the railroad supply industry. New concepts will be costed by identifying components (e.g., valves, electronic chips, batteries) and obtaining quotes from vendors. For both types of equipment, costs are considered in terms of initial equipment, installation, and annual maintenance.

The financial and institutional component of the methodology relies on a number of inputs. The implementation of manpower and operational changes identified through yard and road simulations may first require the revision of labor agreements or laws. Resultant dislocation costs could affect the financial benefits of a candidate system. For example, remote-controlled couplers may allow for the reduction of train crew size. However, experience suggests that railroads may be required to pay unions for many years to compensate for such a change.

The other major inputs to the financial model shown in Figure E.1 are changes in operating, accident and maintenance, and equipment costs, as well as an implementation strategy and a specification of a future scenario. The implementation strategy is particularly important when evaluating a braking and coupling system that would not pay off until a large portion of the car population is equipped. A good example is an electrical train line for cars used in interchange service; clearly, one must strike the right balance of retrofit and new car installation to maximize the return on such a system. Finally, because the development and implementation of new hardware on the railroad system is such a long-term process and because the railroad industry is in a state of flux, future scenarios must be carefully considered to obtain the correct estimate of future costs and benefits.
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1. INTRODUCTION

This study constructs a methodology for evaluating the costs and benefits of advanced braking and coupling systems. It connects various cause-and-effect relations and integrates appropriate databases so the user can evaluate (1) the engineering performance and (2) the effects, both financial and institutional, of implementing innovative components and systems.

The methodology incorporates several important features. First, it permits a user to evaluate alternative systems in terms of financial returns on investments. This is important, since many technically appealing systems may not, in fact, pay off economically. For example, the railroad industry will probably not adapt truly automatic couplers or electrically controlled brakes unless a clearly demonstrated financial benefit exists for doing so. Second, the methodology permits a user to account for significant physical relationships and costs. It is not a simple matter to account for all such factors in an industry as complicated as the U.S. railroad industry - where yard and road operations take place in a variety of ways within and among different railroads. Some judgment must be exercised while selecting cost components for evaluation, or the problem can rapidly become unmanageable. Finally, the methodology enables a user to compute changes in costs corresponding to changes in systems. For example, one can relate changes in railroad collision costs to changes in brake system performance, as measured by stopping distance or other relevant parameters.

Many braking and coupling components and systems have been invented and developed over several decades, but very few have been incorporated into the railroad system. This fact underscores the need for a methodology to evaluate their economic benefits. Many of these new developments, while appearing sound to engineers and other personnel with years of railroad experience, have not been accepted by the industry. The industry's refusal to accept them suggests that these innovations are not cost effective or, perhaps, that their benefits are too subtle to quantify and justify. While the methodology developed here is not a panacea for this problem, it will permit a user to evaluate costs and benefits for a range of major components and systems.

The remainder of this report is organized according to the major components of the methodology discussed in the Executive Summary. The three system inputs - system and components conceptualization, implementation strategy, and future scenario - are described in Sec. 2, while Secs. 3, 4, and 5 discuss the operations, dynamics, and equipment components of the methodology. Sections 6 and 7 treat institutional and financial elements. Section 8 describes the expected output of the methodology. Detail of the yard operation and financial models are included in the appendices.
2. SYSTEM INPUTS

2.1 Component and System Conceptualization

As was illustrated in Fig. E.1, the methodology starts with the conceptualization of components and systems. It is important to identify, first, the present baseline components against which advanced systems and components will be evaluated.

2.1.2 Present baseline freight equipment

The present braking and coupling component baseline* is considered to be:

**Braking System**
- ABDM and ABD brake valves
- Composition brake shoes
- Body-mounted brake rigging
- Single-capacity tread breaks.

**Coupling System**
- Mix of E and F couplers
- Glad-hand air hose connection

While the majority of the present population is equipped with AB and ABD brake valves, all new and rebuilt cars are required to be equipped with ABDM valves. Through attrition, the population will change slowly to ABDM brake valves, and an associated improvement in braking performance will follow. Therefore, the costs and performance of any system used in the future should be compared with the performance of the ABDM valve. While the cost comparison is straightforward and may be carried out directly, the performance comparison is particularly difficult, and must be handled indirectly. This difficulty arises because the Train Operations Simulation Computer Program — the best tool that is currently available for brake system dynamic evaluation — incorporates the functions of the ABD, not the ABDM, valve. Modifying the program to include the ABDM characteristics would be a major undertaking that is beyond the scope of the present program and may not be justifiable at this time. Accordingly, performance will be evaluated in terms of changes from those characteristics associated with the ABD valve. This approach will produce reasonable results as long as one seeks fractional or percentage changes in performance and cost variables from baseline conditions.

*Based primarily on Refs. 1 and 2 and industry reviews.

As with brake valves, a gradual change in the mix of brake shoe type is presently taking place. While the present fleet is equipped with cast iron and composition shoes, performance and cost factors are motivating owners of older cars to convert from cast iron to composition shoes and to specify composition shoes on new cars.

2.1.3 Component identification

Components are the basic elements from which systems are made. Since we do not know at this time which group of components would make the most logical cost-effective system, we identify and deal with basic components in the methodology. The list of components found in Table 1 was compiled from several sources: previous brake system [1] and coupling system [2,3] studies, relevant literature, industry interviews, and our assessment of systems that would fill existing needs. The components have been classified according to whether they are expected to improve operations or dynamics and whether they are mechanical or electrical.

2.1.4 Component conceptualization

Each of the components in Table 1 has a set of performance specifications that can be input into the methodology. In most cases, the performance specifications are qualitative descriptions of the functional changes from the identified baseline system. The exact quantitative value of the change remains indefinite and is treated as a variable to consider a "best possible" and an "achievable" component.

For example, while the performance specification for load-sensitive braking is provision of a braking force proportional to the weight of the car, the specification does not give the exact Net Braking Ratios (NBR) to be considered. The "best possible" component would allow all the cars in a train to be braked at the same NBR. This ideal component would show the largest cost savings that could be realized. An "achievable" component would allow the cars in a train to be braked within a smaller range of varying NBR's than presently exists. This component would represent the cost savings that could realistically be achieved by taking real hardware problems into account, such as discrete two level braking, etc.

Different components will affect different areas of railroad operations and, hence, must be treated by different sections of the methodology. Table 2 presents a summary of the relevant sections.
TABLE 1. IDENTIFIED COMPONENTS AND PERFORMANCE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Improved Operations - Mechanical Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Knuckle Open</strong> - Knuckle is automatically opened upon disengagement from mating coupler.</td>
</tr>
<tr>
<td>2. <strong>Coupler Centering</strong> - When uncoupled, coupler is aligned with the carbody centerline.</td>
</tr>
<tr>
<td>4. <strong>Incompatible Coupler</strong> - A mechanical coupler that is incompatible with present knuckle coupler and that could include integral air and/or electrical connector. Examples include the Willison spread-claw, the flat-face hook, and the pin and funnel.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improved Operations - Electrical Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. <strong>Electrical Connector</strong> - Automatic or manual device that connects one or several electrical train lines.</td>
</tr>
<tr>
<td>6. <strong>Locomotive-Controlled Coupler</strong> - A uniquely addressable coupler that can be opened by a signal transmitted from the locomotive. Includes optional feature of automatically closing air line when activated.</td>
</tr>
<tr>
<td>7. <strong>Automatic Bleed</strong> - Allows brake cylinder or reservoir or both to be gang bled from a remote location.</td>
</tr>
<tr>
<td>8. <strong>Locomotive-Designated Car Brakes</strong> - Uniquely addressable car brake that can be set and released from the locomotive. Can include a mechanical device to prevent undesired release caused by gradual air leakage.</td>
</tr>
<tr>
<td>9. <strong>Ultrasonic Brake Control</strong> - A car-mounted system incorporating an ultrasonic sensor and electronically actuated brakes for controlling the speed of a freely rolling car before impact and coupling with another car.</td>
</tr>
<tr>
<td>10. <strong>Train Condition Monitor</strong> - Adaptable electrical system that allows several variables, such as truck vibration or brake piston travel, to be monitored and transmitted to the locomotive or other station.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improved Dynamics - Alternative Mechanical Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. <strong>Truck-Mounted Brakes</strong> - Brake cylinders are mounted on trucks rather than carbody. Examples are WABOPAC and NYCPAC.</td>
</tr>
<tr>
<td>12. <strong>Disk Brakes</strong> - Provide disk braking surfaces instead of or in addition to conventional tread brakes.</td>
</tr>
<tr>
<td>13. <strong>E Couplers With Shelves</strong> - Provide interlocking shelves on standard E coupler to prevent vertical disengagement.</td>
</tr>
<tr>
<td>14. <strong>High-Strength Couplers</strong> - Couplers manufactured from high-strength steel to mitigate failure under heavy loads.</td>
</tr>
<tr>
<td>15. <strong>Zero Slack Systems</strong> - Couplers and draft gear with no slack to minimize run-out and run-in forces.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improved Dynamics - Electrical Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. <strong>Load Sensor</strong> - Allows the application of a braking force that is proportional to the weight of the car.</td>
</tr>
<tr>
<td>17. <strong>Radio-Controlled Brake Link</strong> - A remote, radio-controlled brake initiation point located in a caboose or radio controlled locomotive.</td>
</tr>
<tr>
<td>18. <strong>Electropneumatic Brakes</strong> - Provide an electrical brake signal to a pneumatic brake system using passenger service technology.</td>
</tr>
<tr>
<td>19. <strong>Electronic Brakes</strong> - An electronic logic network that develops a brake command signal for an electropneumatic control valve.</td>
</tr>
</tbody>
</table>

of the methodology for each of the identified components.

2.1.5 System formulation

Systems of the identified components may be synthesized by using the results of the component evaluation. However, care must be taken to avoid double counting costs or benefits or neglecting synergistic effects. For instance, a system may eliminate the need for a crew member, while any individual component of that system eliminates only work steps.

2.2 Implementation Strategy

2.2.1 Objectives

Implementation strategy is one input to the financial analysis of our methodology; it supplies:
### TABLE 2. SUMMARY OF RELEVANT SECTIONS OF THE METHODOLOGY FOR EACH IDENTIFIED COMPONENT

<table>
<thead>
<tr>
<th>Improved Operations</th>
<th>Operations</th>
<th>Dynamic Effects</th>
<th>Equipment</th>
<th>Financial &amp; Institutional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical and Air Coupling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Knuckle open</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>2. Coupler centering</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>3. Auto air line connector</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>4. Incompatible coupler</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Electrical Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Electrical connector</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>6. Loco-controlled coupler (including angle cock)</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>7. Automatic bleed</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>8. Loco-designated car brakes</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>9. Ultrasonic brake control</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>10. Train condition monitor</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Improved Dynamics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative Mechanical Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Truck-mounted brakes</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>12. Disk brakes</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>13. E coupler with shelves</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>14. High-strength couplers</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>15. Zero slack</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Electrical Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Load sensor</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>17. Radio-controlled brake link</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>18. Electropneumatic brakes</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>19. Electronic brakes</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
1. Number of years before implementation can begin.

2. Number of years from start of implementation until achievement of system benefit.

These two time periods will vary dramatically, depending on the system considered. For example, a system that has already been developed and has received approval from the Association of American Railroads (AAR), such as truck-mounted brakes, could be implemented immediately. A system that is still in the concept stage would pass through research, development, and testing stages before implementation could begin.

Implementation time is different for two basic types of systems:

- A compatible system achieves savings as soon as cars start to be equipped. (Examples of a compatible system are truck-mounted brakes or a load-empty device.)

- An incompatible system does not achieve savings until an entire fleet is equipped. (Examples of incompatible systems include automatic air line connectors and remote locomotive-controlled uncoupling.)

In this section, we develop a reasonable range of times for:

1. Number of years until implementation begins for systems in the conceptual stage.

2. Number of years from start of implementation until system benefit is achieved for incompatible systems.

2.2.2 Years to start of implementation

Any system currently in a conceptual stage would go through six stages before it could be used in railroad freight service. The stages are identified in Table 3.

At this time, it is impossible to predict exact times for each of the identified stages. However, we can estimate a reasonable range of values on the basis of past industry experience with other components. Again, these periods vary greatly, depending on the complexity and required reliability of each component. As Table 3 shows, a reasonable time range from concept to start of implementation, could range from 8 to 17 years.

The length of this procedure is important. To expedite this development process requires a large commitment of resources by the railroad supply industry. In addition, the railroad supply industry might be reluctant to make a commitment without some guarantee of large-scale adoption by the industry. We consider a minimum period of 8 years for the time to begin implementation.

2.2.3 Years to implement systems

Implementation time has an important effect on the financial analysis of an incompatible system. With a large number of identified components and an incomplete knowledge of the limitations of the railroad industry resources, an exact implementation time is impossible to predict. The implementation time will be used as a sensitivity variable, treated within a range of values. The upper and lower bound on this range can be estimated on the basis of previous patterns of railroad implementation of new technologies, along with some simplifying assumptions.

In recent years, the U.S. railroad industry has been slow to implement new technologies. Figure 1 shows the time frame and pattern of adoption for car retarders, centralized traffic control, and diesel locomotives. The process can be roughly characterized as follows: A portion of the industry invests in a new technology, while the remainder of the industry waits to learn from this experience. (This waiting period is reflected in the central plateau seen in Figure 1.) Finally, convinced of the value of the new technology, the remainder of the industry adopts it.

In the past, the process has taken from 20 to 35 years, which is indicative of the time necessary for this industry to adopt at least certain types of technological innovations. Figure 1 is, however somewhat difficult to generalize because the entire U.S. fleet did not have to adopt these technologies to

<table>
<thead>
<tr>
<th>Stage</th>
<th>Estimated Time Range (Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Research</td>
<td>1 - 2</td>
</tr>
<tr>
<td>2. Development</td>
<td>1.5 - 3</td>
</tr>
<tr>
<td>3. Pilot Production</td>
<td>0.5 - 1</td>
</tr>
<tr>
<td>4. AAR Qualification Test Program</td>
<td>2 - 4</td>
</tr>
<tr>
<td>5. Field Testing, Final Debugging</td>
<td>2.5 - 5</td>
</tr>
<tr>
<td>6. Tool up for Production</td>
<td>0.5 - 2</td>
</tr>
<tr>
<td>Total</td>
<td>8 - 17</td>
</tr>
</tbody>
</table>
achieve benefits. Moreover, certain developments, such as dieselization of the locomotive fleet, required massive investments of capital which is not available in limitless quantities.

Incompatible systems are often adopted quickly, but after years of planning. In 1925, after 8 years of planning and preparation, Japan made an overnight conversion of 46,000 cars to incompatible couplers. Russia spent 10 years in preparation and 10 years in changing less than a million cars to incompatible couplers; the project was completed in 1957. The International Union of Railways began studying a European coupler conversion project which it expects will take place in a few week period in 1995 or beyond. These experiences might indicate that a short changeover period is possible, but only after a lengthy period of preparation. However, the relatively large size of the U.S. rail fleet — 1.7 million cars — is an important consideration. In 1969, the U.S. railroads undertook a car-labeling program for the Automatic Car Identification (ACI) system, and 4 years later, 92 percent of the fleet was labeled. This program has perhaps the closest correlation to an implementation program for an incompatible system, because to be effective, the entire system had to be labeled, and it was implemented on the entire U.S. fleet of cars. Car labeling, however, is probably easier than a major braking or coupling system change.

Another consideration is the degree to which the implementation plan disrupts regular service. A fast implementation plan might involve shopping cars that would not otherwise need to be shopped. An implementation plan that coincides with a routine maintenance schedule would be less disruptive. A change of the braking system would fit in naturally with the 12-year clean, oil, test, and stencil (COT&S) period for ABDW brake valves.

The period of implementation should not be longer than the expected lifetime of the new component. A very prolonged implementation plan would obviously require the replacement of components that were never used. Clearly, an optimal implementation strategy would attempt to minimize the total cost of the implementation.

On the basis of this discussion, we consider an implementation time of from 5 to 15 years. This period includes the lower bound of the ACI label program with an upper bound including the scheduled maintenance period of major freight car components. This range implies an aggressive implementation plan.

2.2.4 Summary

We assume an 8-year development and testing period for components currently in the concept stage. We consider an implementation time range of 5 to 15 years; implementation time is treated as a sensitivity variable in the financial analysis.

Only components or systems determined to be economically beneficial are considered for a final implementation strategy. Judgment of economic benefit is based on the economic analysis with the preliminary implementation time assumption.

2.3 Future Scenario

We consider the future size and structure of the freight rail system in the process of determining the net benefits from advanced braking and coupling technology. Proposed concepts will not be implemented on today's rail system, but on some future system. In this section, we develop a baseline future scenario for evaluating potential benefits from advanced technology. This scenario includes:

- A time horizon for the future
- Rail system variables important to an evaluation of benefits from advanced braking and coupling technology
- Projections of the way in which specified variables change over time.

2.3.1 Time horizon

The time horizon for the future scenario is dictated by the time requirements of a series of events that must occur before a user can realize all
potential benefits. These events can be segmented into three categories, as shown in Table 4.

TABLE 4. FUTURE TIME HORIZON

<table>
<thead>
<tr>
<th>Event Category</th>
<th>Time Requirement (Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Research and development, testing, and production tooling</td>
<td>8</td>
</tr>
<tr>
<td>(time span from idea stage to AAR-approved production components ready for system implementation)</td>
<td></td>
</tr>
<tr>
<td>2. First implementation to realization of benefits*</td>
<td>0 - 15</td>
</tr>
<tr>
<td>3. Years of benefit from advanced systems</td>
<td>10 - 25</td>
</tr>
<tr>
<td>Total time required to realize savings from advanced systems</td>
<td>18 - 48</td>
</tr>
</tbody>
</table>

*Concepts that require compatibility (e.g., train electrification) will realize no savings until the entire interchange fleet is fitted with the necessary hardware. Other concepts (e.g., load-proportional devices) will realize savings immediately upon implementation.

Time requirements for categories 1 and 2 were developed in Sec. 2.2. A time span of 10 to 25 years is considered a reasonable range for the lifetimes of advanced system hardware.

The total time required to realize savings, 18 to 48 years, projects to 1997 and 2027.

2.3.2 System variables

Advanced braking and coupling systems have the potential to generate savings in the following areas: yard and transportation labor, accidents,* car utilization, and freight car maintenance. Rail system variables important in evaluating the level of potential savings in these areas are listed in Table 5.

2.3.3 Projection of changes in system variables

Our analysis indicates that the variables in Table 5 are not expected to change dramatically over time. This conclusion is based upon recent studies on the future of the freight rail system [4]. Variables that will change are shown in Table 6, and explanations of the development of these projections follow.

TABLE 5. RAIL SYSTEM VARIABLES TO BE PROJECTED

<table>
<thead>
<tr>
<th>System Variables</th>
<th>Related Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of freight cars in railroad service</td>
<td>Yard and transportation labor</td>
</tr>
<tr>
<td>2. Number of daily switching operations</td>
<td>Yard and transportation labor</td>
</tr>
<tr>
<td>3. Number of railroad yards*</td>
<td>Yard and transportation labor</td>
</tr>
<tr>
<td>4. Average over-the-road train speed</td>
<td>Car utilization</td>
</tr>
<tr>
<td>5. Average freight car capacity</td>
<td>Freight car maintenance</td>
</tr>
<tr>
<td></td>
<td>Accidents</td>
</tr>
<tr>
<td>*Includes both industry and classification yards.</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 6. PROJECTED CHANGES IN FREIGHT RAIL SYSTEM VARIABLES TO YEAR 2000**

<table>
<thead>
<tr>
<th>Years</th>
<th>Percentage Change Over Time Period (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>2000</td>
</tr>
<tr>
<td>1. Number of freight cars in railroad service (thousands)</td>
<td>1,655</td>
</tr>
<tr>
<td>2. Number of daily switching operations (thousands)</td>
<td>915</td>
</tr>
<tr>
<td>3. Number of classification yards</td>
<td>1,172</td>
</tr>
<tr>
<td>4. Average over-the-road train speed (mph)</td>
<td>47.5</td>
</tr>
<tr>
<td>5. Average freight car capacity (tons/car)</td>
<td>80</td>
</tr>
</tbody>
</table>

Number of Freight Cars in Railroad Service

The expected number of freight cars in future railroad service is developed from a straight line least squares projection of AAR data for years 1963 to 1978 as shown in Figure 2.

Number of Daily Switching Operations

From a projection of present trends,† Stanford Research Institute (SRI) [4]

†Stanford Research Institute also makes projections for changes in daily switching operations, given an energy crisis scenario and a super rationalization scenario (this scenario assumes a speeded-up implementation of a number of proposals for improving railroads). Because of the uncertainty that accompanies predictions of the rail freight [footnote cont'd. on next page]
estimates a relatively small increase in the daily number of switching operations over the 1980 to 2000 time period. This projection is shown in Figure 3. Car switching operations increase from approximately 915,000 in 1980 to 941,000 in 2000. In the development of this estimate, projections of present trends in a number of factors influencing car switching operations are accounted for; these include economic conditions, rail freight demand, car capacity, average length of road haul, merger activity, use of unit trains, and intermodal operations.

**Number of Railroad Classification Yards**

The number of railroad classification yards is expected to decrease by approximately 17 percent during the 1980-to-2000 time period. This estimate is developed from an analysis of projected changes in railroad classification yards shown in Table 7 and adopted from Ref. 4.

The projections developed in Ref. 4 apply to the 1975-1985 and the 1985-2000 time periods. To estimate values for 1980, which is of interest to us, we assume the construction activities take place evenly over the 1975-1980 period, and determine that there will be a net decrease of approximately 113 yards during this period.

<table>
<thead>
<tr>
<th>TABLE 7. RAILROAD CLASSIFICATION YARD INVENTORY AND REQUIREMENTS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yards downgraded or abandoned</td>
</tr>
<tr>
<td>Yards expanded, reconfigures or constructed new</td>
</tr>
<tr>
<td>Net change during time period</td>
</tr>
</tbody>
</table>

*Adopted from Ref. 4, p. 66.
† Assumes uniform construction activity over time.
A decrease of 57 in yards from 1975 to 1980. Similarly, there is an additional decrease of 201 yards by the year 2000.

Thus the yard inventories for 1980 and 2000 are given below:

<table>
<thead>
<tr>
<th>Year</th>
<th>Yard Inventory</th>
<th>Net Change 1975-1980</th>
<th>Year</th>
<th>Yard Inventory</th>
<th>Net Change 1980-2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>1229</td>
<td>(57)</td>
<td>1980</td>
<td>1172</td>
<td>(201)</td>
</tr>
</tbody>
</table>

Average Over-the-Road Train Speed

Average over-the-road train speed is estimated from a straight line extrapolation of recent projections shown in Figure 4 below. This extrapolation results in a 9.4 percent increase in train speed over the 1980-to-2000 time period.

Average Freight Car Capacity

Estimates of freight car capacity are useful to estimate the parameters of future consists. Figure 5 shows historical data [6] and several projections of freight car capacity and load. In 1978 the average capacity of new cars was 90 tons. One would expect the fleet average to reach this level over the course of years, as suggested more by the 1960-1977 trend extrapolations [6] than by the projection of carload size [4] that shows a marked change in slope. Accordingly, it appears reasonable to assume that by 1980 average freight car capacity will be 80 tons and that by 2000 it will be 100 tons.

2.3.4 Baseline future scenario

We will adopt the projections for the year 2000, listed in Table 6, as our baseline scenario for evaluating benefits from advanced braking and coupling technology. The following discussions consider alternative future scenarios.

Alternative Future Scenarios

The baseline future scenario presented above was developed from projections of present trends in the railroad industry and therefore does not account for possible occurrences that may have dramatic impact upon railroads. Although attempts have been made to project changes quantitatively in the railroad industry on the basis of assumed future scenarios, our sense is that quantitative projections of this sort, especially over a 20-year time horizon, are likely to be inaccurate.

Listed below are a number of important and interrelated factors that will affect the size and structure of the future freight rail system.

- Government Policy Towards Railroads
  - Deregulation
  - Light density line abandonments

* SRI developed an energy crisis scenario and a super rationalization scenario to project changes in the number of railroad classification yards; see Ref. 4.
Merger activity
  Freight rate changes
  - Intermodal competition
  - Financial assistance
  - Yard relocation
  Ownership Changes and Cooperative Arrangements Among Railroads
  - Line, branch, terminal rationalization
  - Network changes
  - Improved blocking strategies
  Economic Conditions
  - Level of economic activity
  - Structural changes in economy
  - Railroad profitability
  Energy
  - Fuel availability
  - Coal production.

Given the enormous difficulty in projecting, with any degree of accuracy, the future condition of these factors, alternative scenarios have not been developed for this analysis.
3. OPERATIONS

3.1 Objectives and Scope

To evaluate operations, the methodology accounts for changes in manpower and equipment and the associated differential costs or benefits between conventional and advanced systems. The primary change to be assessed is the performance of a number of tasks more quickly by fewer people with advanced systems. Most tasks involving improved coupling systems speed the flow of cars through classification yards and accelerate the delivery and pickup of cars at sidings and industrial yards.

The major factors and assumptions to evaluate operations are:

The minimum crew size must be determined by the task that requires the largest number of people. One of the potential financial benefits of an advanced coupling system is a reduction in manpower. Crew size is logically determined by the task requiring the largest number of participants, though labor/management negotiations also affect the size. Thus, it is essential to ensure that these tasks are addressed in the methodology.

Equipment and labor time required for each task must be accounted for. Clearly, the greatest operational benefit of advanced systems involves the more efficient utilization of equipment and personnel. Accordingly, it is necessary to account for direct as well as indirect time savings. For example, when automatic air line connectors are evaluated, the methodology must account not only for the direct savings of time to couple hoses manually, but also the indirect savings of time used by a crewman walking from car to car.

Time saved is, on the average, used effectively. This assumption is perhaps the most difficult to justify. Basically, it assumes that the railroad system will accommodate increased efficiencies so that time saved during one stage of an operation is not wasted during the subsequent stages. While no data confirm this assumption directly, there are data that tend to support it.

Figure 6 illustrates the relation between late arrivals and late departures from over 13,000 cars processed through one hump and two flat yards [7]. The data show that even when inbound trains arrive on time or early, there is an average delay of about 5 hr in outbound trains, resulting primarily from cancellation of outbound trains. Of greater interest to our work is the slope of the least squares linear regression curves shown in the graphs. These curves show that an incremental hour of inbound delay results in 0.62 to 1.48 hr of additional outbound delay—or roughly, each hour of inbound delay results in an hour of outbound delay. Presumably, the amount of time saved in classifications would be equivalent to an equal reduction in outbound lateness. Thus, it appears that our assumption is in accord at least with these data.

![Figure 6. Mean outbound lateness versus inbound lateness [7].](image-url)
3.2 Development of Methodology

Many of the benefits associated with advanced braking and coupling systems occur at the most fine-grained level of yard and road operations. An automatic brake bleed device precludes the need for car inspectors to stop momentarily at each car to discharge cylinder and reservoir air. While this time savings may be credited to the device, there is no leverage effect, since inspectors must still walk along the train in search of defective cars and components. In contrast, an uncoupler controlled by an engineer in a locomotive cab may save not only the small amount of time required for a trainman to lift the cut lever, but also the often greater amount of time required to walk from one end of a long train to the appropriate coupler. Accordingly, it is essential to account not only for the direct time associated with an operation but also the indirect time, as appropriate.

To account for all the potential time and labor savings associated with each component or system and also to account for differences among yard and road operations, we have modeled yard and local delivery operations in terms of probabilistic operational models. The essential features of the models are demonstrated by the somewhat generalized elements illustrated in Figure 7. The example model accounts for the flow of cars from point A to B through the decision point Q1 and time elements designated by T1, T2, and T3. The decision point accounts for different ways of handling trains or cars in a given yard or among many different yards. The outcome is a probability that cars will flow along one operational path or the other. The times T1 simply designate the amount of time consumed in processing a string of cars or an individual car. The average time T required to process cars from A to B simply becomes

\[ T = p_1 T_1 + p_2 T_2 + T_3 \] (1)

3.3 Classification Yard Model

The structure and detailed operations in classification yards vary considerably, depending on yard capacity, railroad needs, geographical conditions, availability of various types of equipment, preferred styles of personnel, and a variety of other factors. Large, modern yards that classify several thousand cars daily will typically have one or more humps with computer controlled switches and retarders for rapid classification. Most yards, however, are flat and classification is performed by a four-man crew and locomotive that "kicks" cars (individually or in small groups) onto classification tracks.* Our models account for these two basic types of classification yards — hump and flat. Within each category we have constructed a model which we believe is a reasonable representation of all yard operations, though it will not simulate the large variation in yard procedures. Its purpose is to provide a reasonable evaluation of alternate braking and coupling systems rather than a means of evaluating alternate yard operating techniques.

The complete yard model involves about 150 individual operations and a dozen decision points. This level of detail, though necessary, becomes tedious for most readers, and is described in Appendix A. Here we will describe only the major elements and structure of the model, as illustrated in Figure 8.

The first stage of yard operations involves the actual yarding of a train. When an inbound train arrives, it is assigned to one or two tracks, depending on the length of the train and the available track space. The parameters p1 and p2 designate the respective probabilities that one or two blocks of cars will be required. If there is sufficient room on one track, the top path of the yard train segment in Figure 8 applies and simply involves the movement of the train to the receiving track, after which several hand brakes are applied. If the train is to be split, the bottom path applies. In this case, it is necessary, first, to uncouple the train near its center, apply

*In this operation a locomotive pushes a string of cars forward and a trainman walks or runs along to uncoupler one or several cars that are destined for a predetermined classification track. He lifts the coupler operating lever and the engineer applies the brakers to the locomotive, allowing the designated cars to roll forward onto the appropriate track. The process is repeated until all cars in the string are classified.
air brakes or several hand brakes on the rear block, and move the first block to a receiving track. A road or switch locomotive then moves to the waiting block and couples to it. Car brakes are released, and the block is moved to a second receiving track where brakes are again applied. Regardless of whether a train was yarded in one or two blocks, an inbound inspection takes place, during which air brakes are bled.

The second stage in Figure 8 is the train classification. A locomotive is coupled to waiting cars, hand brakes are released, and a block is moved to a switch or hump lead. For each car, the train crew decides (on the basis of instructions) whether the car is to receive special handling. If it is, the car will be spotted, or a brakeman will ride with it to apply the hand brakes and avoid high-speed impact with other cars that may be on the designated classification track. If not, the car is simply pushed over the hump or kicked, depending on the type of yard.

The third stage is called the pull down, in which outbound trains are assembled from blocks of cars waiting on classification tracks. For each block, a switch engine is coupled to the lead car, and the block is trimmed.* Trimming involves coupling cars that failed to couple during classification. As indicated in Figure 8, miscoupling may occur for any of a number of reasons. A car may stop short or rebound; couplers may

*Trimming may be performed by the switch crew immediately after classifying a group of cars. For our purposes, the stage at which we account for this operation has no impact on the final results.
bypass or break; or the lock might not drop. After all cars are coupled, the block is moved to the departure track. The switch engine returns repeatedly to the classification tracks to "pull down" all remaining blocks on the departure track.

The final stage in yard operation is the power brake test. Car air hoses are coupled and the brakes are charged either by a yard air supply or by a locomotive. After the brakes are charged, the pressure at the rear of the train is measured to ensure that it is greater than 60 psi and within 15 psi of the feed valve pressure. If this criterion is met, the test proceeds; if not, the crew must diagnose and remedy the problem. Then, a 15-psi service reduction is applied, the brake valve lapped, and the leakage rate measured. If the leakage rate is less than 5 psi/min, the test continues; otherwise, the crew looks for excessive leakage within the train and takes corrective action. A full service reduction is then applied, and the train is inspected to ensure that angle cocks are properly positioned, brakes have applied on each car, the piston travel is within tolerance on each car, and brake equipment is in proper condition. The brakes are released, and the train is inspected again to ensure that all brakes have indeed released. The train then departs.

### 3.4 Coupler Gathering Range Assessment

Coupler bypasses may cause damage and delays. Increasing the coupler gathering range may reduce such bypasses. To assess the benefits of larger gathering range, the probability that couplers will couple upon impact must be evaluated.

Figure 9 illustrates the problem. The distribution of the position of Coupler A is represented by the probability density function p(y). The position y = 0 corresponds to the location the coupler would move to if it were coupled to another car and put in draft. The coordinate y is positive if the coupler, as viewed standing on the track and looking at the end of the car, is moved to the left. Note that the distribution of Coupler B is the same as that of Coupler A, except that one has to pay close attention to the positive and negative directions.

If Coupler A is in position y, then the probability that Coupler B will couple with it is given by

\[
\int_{-(y+g_1)}^{-(y-g_2)} p(x) dx
\]

where \( g_1 \) is the amount one can displace the centerline of Coupler B.
with respect to the centerline of Coupler A, so that the knuckles move closer together and still have the couplers make;

\[ g_2 = \text{the amount one can displace the centerline of Coupler B with respect to the centerline of Coupler A, such that the knuckles move further apart, and still have the couplers make.} \]

The values \( g_1 \) and \( g_2 \) depend on whether just one or both couplers are open.

The probability that Coupler A lies between \( y - 1/2 \delta y \) and \( y + 1/2 \delta y \) is \( p(y) \delta y \). Combining this with the above gives the following value for the probability of coupling as a function of \( g_1 \) and \( g_2 \) for all values of \( y \):

\[ P(g_1, g_2) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p(y)p(x) \delta x \delta y . \] (3)

The above model assumes the following limitations:

1. \( g_1 \) and \( g_2 \) are deterministic—that is, the couplers are always open or closed but not in an intermediate position.

2. \( g_1 \) and \( g_2 \) are independent of any angle the shanks may make relative to each other, but depends only on the relative position of their centerlines.

In this respect the model is valid only for tangent track or two similar cars on curved track of constant radius. It does not apply to cars on curved track with different overhangs or for cars on adjacent portions of curved track with different radii.

Figure 10 presents some preliminary data for the probability density function \( p(y) \). These data were measured in the Boston and Maine West Cambridge Yard for couplers on the free ends of cars, presumably in a position where they are waiting to be coupled to other cars. We made an effort to measure only cars on tangent tracks; whether the cars were on curved or tangent track was determined simply by looking down the track for a distance of approximately 100 ft from the car. For all cases, the type of coupler and whether or not the car had any special features (such as a centering device) were noted.

Although the distribution illustrated in Figure 10 shows a range of only ±3 in., it is clear that the short shank couplers could be 3 or 4 in. farther to one side or the other and that the long shank couplers could be moved perhaps as much as 8 or 9 in. in either direction. The probability of finding a coupler near these extreme positions is most likely very low, implying that a large number of measurements would have to be conducted to develop some confidence in the value of the density function for large displacements. However, these large displacements are also the ones that lead to bypasses and, consequently, large expenses. A summary report on coupling systems [2] stated significant bypass damage occurs once every 4 or 5 years on long shank cars. This implies that the probability of a coupler being in a position to cause such a bypass is most likely less than 1 in 1000. On the other hand, one would expect the distribution to peak more sharply near the center. Clearly, many more measurements should be made to refine the distribution shown in Figure 10.

To demonstrate the model, we will consider a somewhat simplified example. First, we will simplify the actual measured distribution shown in Figure 10 to the rectangular distribution shown by the dotted line. This is not necessary, but it greatly simplifies the mathematics for the sake of an example. Next, we note that by making a change in variables and interchanging the order of integration, Eq. 3 can be written as

\[ P(g_1, g_2) = \int_{-g_2}^{g_2} \int_{-\infty}^{\infty} p(y)p(z-y) \delta x \delta y . \] (4)

This form is much easier to handle, especially for the simplified rectangular distribution discussed above.

The rectangular distribution shown in Figure 10 can be expressed mathematically as

\[ p(y) = \begin{cases} 
0 & , \quad y < -3 \\
1/6 & , \quad -3 \leq y \leq +3 \\
0 & , \quad y > +3 .
\end{cases} \] (5)
Substituting this into Eq. 4, gives

\[ P(g_1, g_2) = \int_{-g_1}^{g_2} f(z) \, dz , \]  

(6)

where \( f(z) \) is as shown in Figure 11. The integration from \(-g_1\) to \(g_2\) is the shaded area; however, it is easier to subtract the area of the two unshaded triangles from the total area. This procedure gives the following expression

\[ P(g_1, g_2) = 1 - \frac{1}{12} (g_1 - 6)^2 - \frac{1}{12} (g_2 - 6)^2 . \]

(7)

This expression is plotted in Figure 12, which presents contours of constant values of \( P \) as a function of \( g_1 \) and \( g_2 \). For values of \( g_1 \) and \( g_2 \) less than 6 in., the contours of constant \( P \) are circles centered at \( g_1 = g_2 = 6 \) in. For either \( g_1 \) or \( g_2 \) greater than 6 in. but not both, the contours are straight lines; and for \( g_1 \) and \( g_2 \) greater than 6 in., \( P = 1 \).

For this example, the probability of coupling with a gathering range of 4 in. (i.e., \( g = 4 \)) is approximately 0.5. This would correspond to the case of two open E couplers. If the gathering range were increased to 8 in. (i.e., \( g_1 = g_2 = 8 \) in.), the probability of coupling would increase to approximately 0.9. Clearly, a value of 0.5 for \( g_1 = g_2 = 2 \) in. seems low. This is probably due to the distribution of our pilot data, and our subsequent simplified rectangular approximation. The pilot data may not be as sharply peaked as expected, because some cars may have been measured on slightly curved tracks. This would have the effect of moving the couplers off to one side or the other, thus causing the flatter distribution. The methodology extends to handle data acquired on curved and tangent track.

### 3.5 Road Model

Track layouts for industrial sidings can have a number of configurations. There may be one or several tracks with cars to be picked up and/or delivered from each. For purposes of this study we have modeled a single siding as shown in Figure 13. This configuration requires all essential braking and coupling operations that are employed in more complex situations.

The road model for local pickup and delivery is conceptually similar to the yard model discussed in Sec. 3.3, but involves fewer steps. A simplified schematic diagram of the model is shown in Figure 13. Figure 14 is a diagram of the road model for local pickup and delivery. The operation begins when a train arrives at a siding. The first decision is whether or not cars are waiting to be picked up. If not, the crew proceeds to set cars out. If cars are to be picked up, the crew uncouples the locomotives from the rest of the train and moves forward past the turnout. The switch is thrown and the locomotive is backed until it couples with the waiting cars. The air hoses are connected, brakes are charged, and the cars are pulled back past the switch to the branch or main line. The switch is thrown again and the locomotive and cars are backed and coupled to the waiting train. Air hoses are coupled and brakes are charged.
If cars are to be set out, the last car in the block, marked "delivery" in Figure 13, will be uncoupled and the cut moved forward past the turnout. The operation proceeds as with the pickup. The cars are backed on to the siding, the delivery block is uncoupled, and the locomotive and attached cars are returned to the line and backed and coupled to the waiting cars. Brakes are charged and tested, and the train departs.
4. DYNAMICS

4.1 Objectives and Scope

Advanced braking and coupling systems may improve train dynamics by reducing stopping distance and in-train forces. Stopping distance reductions, in turn, would provide benefits by reducing the frequency and severity of collisions. Lower in-train forces are expected to reduce the frequency of draft gear failure over the road, with concomitant reductions in train delays, derailments from running over a broken component, and broken-train collisions that occur when the rear portion of a separated train catches up and runs into the front portion. To evaluate dynamics, the methodology accounts for the degree to which existing costs associated with these problems would be changed by advanced systems.

The major factors and assumptions to evaluate dynamics include the following:

Faster responding brake systems, will not significantly decrease the costs of grade crossing accidents. This regrettable assumption has been deduced from a review of FRA and National Transportation Safety Board (NTSB) accident reports and from conversations with several knowledgeable railroad managers in the public and private sectors. The research showed that when a train ran into a motor vehicle or pedestrian, the train was usually close to a crossing and, to avoid a collision, would have had to increase the deceleration rate by orders of magnitude. In many other cases, motor vehicles ran into the sides of trains, and the engineer had no advanced warning of the impending accident.

FRA statistics, adjusted for clean-up and lading damage expenses, are reasonable first-order indicators of direct costs of accidents. The FRA requires that railroads report accidents only when the direct costs to equipment, track, and signals exceed a specified threshold level (e.g., $2300 in 1977). While this requirement avoids the administrative burden of reporting all of the lower cost accidents, it does bias the data conservatively. That is, actual costs will exceed those based on FRA data, but since it is not practical to obtain all cost data, we will use FRA data.

4.2 Procedure

The effects of changes in train dynamics on accident and maintenance costs can be evaluated in at least two ways. First, one can build up to the results from basic principles through a series of cause-and-effect relationships. Starting with fundamental physical dynamic and material properties, one can analyze a given braking and coupling system by simulating accidents and component failures for a "representative" number of scenarios. It would then be theoretically possible to evaluate each candidate system this way and identify the best system. Of course, the data are not available to determine representative scenarios, nor is the state of the art sufficiently advanced to simulate the damage that occurs in railroad accidents. The second approach — and the one that we use — is to start with baseline accident and maintenance data for the present system and evaluate perturbations from them. For example, we may never know precisely the complex forcing history of couplers. But if we know the existing fatigue lives of couplers and can devise a braking and coupling system that reduces coupler forces by about the same amount in most situations, we can predict with some confidence the extended fatigue life of couplers.

Figure 15 provides an overview of the analysis that is oriented primarily toward over-the-road dynamic effects of trains. Generally, the analysis uses a train and brake system model to calculate stopping distances and coupler force levels. We use the Train Operations Simulator (TOS) developed by the AAR to compute these dynamic variables. Stopping distances for advanced systems are then normalized by stopping distances for baseline existing systems, and they form the input to a collision cost analysis. This analysis uses baseline collision costs to estimate the incremental costs of an advanced system.

Coupler forces for an advanced system are normalized by those for the present baseline system to obtain a ratio of forces or (more meaningfully) stresses. These stresses are the input to a fatigue failure analysis in which the ratios of road failures and of total failures are computed. The road failure ratio, coupled with baseline road failure data and train hourly delay costs, allows us to estimate total delay costs. Over-the-road failures of couplers and associated draft gear also occasionally cause derailments and broken-train collisions, which are accounted for as well. Finally, fatigue damage accumulated over the road simply reduces the life of components, which may be taken into account in a similar manner.

While most of this section deals with road train dynamics, one of the systems identified in Table 1 has the potential of significantly reducing car-to-car dynamic impact forces in yards. The ultrasonic brake control senses an impending impact and automatically reduces...
car speed as necessary to provide for a gentle but positive coupling. The benefits from reducing these forces are expected to be primarily reductions in coupler failure and lading damage. These effects will be treated in Secs. 4.6 and 4.7.

4.3 Inputs and Train Operations Simulator (TOS) Model

Command and Parametric Inputs

The train parameters used to evaluate baseline and advanced systems are:

- **Locomotives**: 3 SD40
- **Cars**: 100 L85 boxcars — 30-ton tare weight, 130-ton gross weight, 1 caboose at 23 tons
- **Brake Shoes**: Composition
- **Operating Valve**: ABD*
- **Brake Pipe Pressure**: 80 psi
- **Brake Pipe Leakage Rate**: 3 psi/min
- **Coupler**: Type E
- **Draft Gear**: Mk50

*The TOS model is not capable of simulating the newer ABDW valve. As discussed in Sec. 2, dynamic performance must therefore be viewed as fractional changes from baseline values, rather than in absolute terms.

The brake command signals and the track and train parameters have been configured to provide a range of values for the TOS model outputs (stop distance and coupler forces). Table 8 shows a data matrix for collision analysis. For collisions, stopping distance is the important variable, and we assume emergency brakes are always applied. Stopping distance will depend strongly on the initial train speed, the degree to which cars are loaded, and the track grade. Since curvature is not expected to be a significant factor, we consider only tangent track.

As illustrated in Table 9, in-train force levels for component failures are based primarily on load distributions, speed, and level of brake application. We have chosen four levels of brake application corresponding to a minimum service reduction of 6 psi, a partial reduction of 15 psi, a full-service reduction (23 psi for an initial brake pipe pressure of 80 psi), and an emergency application. Since car run-in and concomitant generation of in-train forces is greater for loaded than for empty trains, we configure

*On occasion, locomotive engineers will hesitate to apply emergency brakes before a collision for fear of derailing the train [8].
TABLE 8. STOPPING DISTANCE FOR COLLISION ANALYSIS. EMERGENCY BRAKING MODE AND TANGENT TRACK APPLY.

<table>
<thead>
<tr>
<th>Grade</th>
<th>% Loaded</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>+1%</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>-1%</td>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>

Note: 1. Load distribution (head to rear) 25 empty, 25 loaded, 25 empty, 25 loaded cars.

TABLE 9. IN-TRAIN FORCE LEVELS FOR COMPONENT FAILURE ANALYSIS. LEVEL GRADE AND TANGENT TRACK APPLY.

<table>
<thead>
<tr>
<th>Level of Braking</th>
<th>Load Distribution</th>
<th>Min (6 psi)</th>
<th>Partial (15 psi)</th>
<th>Full (23 psi at 80 psi app)</th>
<th>Emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Loaded</td>
<td>25E*</td>
<td>25E</td>
<td>25E</td>
<td>25E</td>
</tr>
<tr>
<td>Speed (mph)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>25E</td>
<td>25L</td>
<td>25L</td>
<td>25E</td>
<td>25L</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*E indicates empty; L indicates loaded.

one consist of all loaded cars. Also, as shown in two studies [9,10], loaded cars at the rear of a train with empties near the head end create particularly high compressive loads. Accordingly, we adopt the car loading distribution, from front to rear, of 25 empties, 25 loads, 25 empties, and 25 loads.

TOS Model

To evaluate the influence of various parameters on braking performance, we use the Train Operations Simulator (TOS) model developed by the AAR. The TOS model is a versatile digital computer program that simulates a train during longitudinal maneuvers. The model accounts for numerous factors, including the finite propagation speed of pressure waves along the brake pipe, the complex response of brake valves, the rigid-body dynamics of freight cars and locomotives, draft gear compliances, and externally applied forces to each car. The model has been periodically updated; Release No. 3 (November 1977) is the latest version available and the one that we use.

Figure 16 shows a comparison of an actual train velocity versus time profile and a profile predicted by TOS, for a power braking split service application of a fully loaded coil steel train. The agreement between the two profiles is very good. Figure 17 shows a comparison of actual coupler forces for car 21 of the train and the coupler forces predicted by TOS. The correlation is very good for the steady state section of the braking; i.e., 50 to 110 sec. However, there is a large error in the transient sections of the run. A runout that occurred at approximately 40 seconds was predicted by TOS to occur at 18 seconds with a much smaller amplitude. There is also a question of accuracy right after the train has stopped. It is important to be aware of the inaccuracies in the analysis of the output to avoid comparisons based on data in these areas of little confidence.

4.4 Collision Analysis: The Value of Decreased Stop Distance

The ability to stop a freight train faster has two potential direct benefits:

- The potential for avoiding accidents and for saving related costs at present track speeds;
- The potential for increasing track speeds and for realizing the related improvement in utilization where track speeds are currently limited by the signal spacing.

We do not consider this second benefit, but it deserves a brief comment. Track speeds could be increased only in areas where speeds are currently limited by the need for a loaded train to stop within one signal spacing, rather than other factors, such as track condition and terrain. Of these areas, only those tracks that are currently used to maximum potential would benefit by being able to move more trains over a section of track.

A survey of mainline utilization in selected areas (see Table 10) indicates that most mainline track is not being used to maximum potential.

Because of these observations and because line haul operation currently represents only 14 percent of a car's load-to-

TABLE 10. MAINLINE CAPACITY UTILIZATION IN SELECTED AREAS [4].

<table>
<thead>
<tr>
<th>Selected Area</th>
<th>Estimated Percent Typical Utilization (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Seaboard to the Alleghenies (Harrisburg/Cumberland)</td>
<td>25</td>
</tr>
<tr>
<td>Mainlines through the Alleghenies to Pittsburgh</td>
<td>40</td>
</tr>
<tr>
<td>New York and New England to Buffalo</td>
<td>20</td>
</tr>
<tr>
<td>East-West mainlines in central Ohio</td>
<td>30</td>
</tr>
<tr>
<td>North-South mainlines in central Ohio and central Indiana</td>
<td>23</td>
</tr>
<tr>
<td>Mainlines into St. Louis</td>
<td>23</td>
</tr>
<tr>
<td>Mainlines into Chicago</td>
<td>30</td>
</tr>
<tr>
<td>Mainlines through Rocky Mountains</td>
<td>45</td>
</tr>
<tr>
<td>Los Angeles to the North</td>
<td>40</td>
</tr>
<tr>
<td>Los Angeles to the East</td>
<td>45</td>
</tr>
</tbody>
</table>

load cycle time, the improvement in utilization resulting from improved braking is expected to be small. Increasing the track speed would to some degree negate the potential for accident savings. Therefore, only the potential for reduced accident costs was considered as a benefit from decreased stop distance.

4.4.1 Accident cause codes considered

Railroad accidents have many causes. Because increased stopping ability can affect accident costs only through shorter stopping distances and resultant lower impact velocities, we consider accidents that meet two conditions:

1. The accident could be avoided or reduced in severity by a shorter stopping distance;
2. The engineer could be aware of the impending accident with sufficient time and distance to achieve the improved stopping.

These two accidents require a judgment based on the type and cause of the accident. The only complete sources of accident data are the FRA accident reports and statistics. The FRA cause codes [12] are not detailed enough to make this determination with a great degree of accuracy. We based our decision to include or exclude a specific cause code largely on a consensus of several informed persons. Generally, mechanical failures of components were excluded, and human and communication failures were included. Brake component mechanical failures were excluded because we feel that alternate braking systems, while their mechanical failures may be of a different nature, would still experience mechanical failures. Since we were
unable to project the types and quantity of failures, we assumed that the mechanical failure rate would remain unchanged. We judged that the following FRA accident cause codes [12] were dependent on shorter stopping distances:

Signal and Communication Failures

202 Fixed signal, improperly displayed (defective)
201 Radio communication equipment failure
202 Other communication equipment failure
209 Cause code not listed; enter Code 209 in Item 35 and explain in Item 50

Flagging, Fixed, Hand, and Radio Signals

519 Fixed signal, improperly displayed
520 Fixed signal, failure to comply
521 Flagging, improper or failure to flag
522 Flagging signal, failure to comply
523 Hand signal, failure to comply
524 Hand signal, improper
525 Hand signal, failure to give/receive
526 Radio communication, failure to comply
527 Radio communication, improper
528 Radio communication, failure to give/receive
529 Cause code not listed; enter Code 529 in Item 35 and explain in Item 50

Other Rules and Instructions

530 Car(s) shoved out and left out of clear
531 Cars left foul
533 Failure to stop train in clear
535 Instruction to train/yard crew, improper
536 Motor car or on-track equipment rules, failure to comply
541 Special operating instruction, failure to comply (identify instruction in Item 50)
542 Train order, or timetable authority, failure to comply
543 Train orders, radio; error in preparation, transmission, or delivery
544 Train orders, written; error in preparation, transmission, or delivery

4.4.2 Direct costs

The FRA accident data tape [12] contained information for the three-year period from 1975 through 1977. The accident costs for the cause codes listed above were collected for all types of collisions, excluding highway crossing accidents and derailments (see Table 11).

Table 11 shows the direct accident costs for each type of accident for 1975 through 1977 (equipment, track, and signal damage). The total costs for 1975 and 1976 are in close agreement, but the 1977 total cost increases approximately 200 percent from previous years. (The reporting threshold was changed between 1976 and 1977, from $1750 to 2300.) This large jump is hard to explain since the number of accidents considered in Table 11 is relatively small. A comparison of this trend with trends to the more general accident cost figures of Table 12 is helpful. The total accident cost for all train accidents grew at a rate of 28 percent between 1975 and 1976, and 23 percent between 1976 and 1977. This growth does not exhibit the large cost growth rate found in Table 11 between 1976 and 1977, indicating a consistency in the data collection from year to year. If the human factors category in Table 12, which includes most of the identified cause codes, is considered, the accident cost growth rate is 6.5 percent between 1975 and 1976 and 106 percent between 1976 and 1977. This large growth rate, while not as large as 200 percent, is based on many more accidents (2,559 versus 339), and therefore indicates that

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Head On</td>
<td>14</td>
<td>362,269</td>
<td>33</td>
<td>1,776,917</td>
<td>5</td>
<td>4,334,119</td>
</tr>
<tr>
<td>Rear End</td>
<td>42</td>
<td>3,648,127</td>
<td>58</td>
<td>987,753</td>
<td>52</td>
<td>6,365,230</td>
</tr>
<tr>
<td>Side</td>
<td>97</td>
<td>882,005</td>
<td>134</td>
<td>1,401,000</td>
<td>238</td>
<td>2,616,918</td>
</tr>
<tr>
<td>Raking</td>
<td>29</td>
<td>193,647</td>
<td>26</td>
<td>236,079</td>
<td>38</td>
<td>1,025,476</td>
</tr>
<tr>
<td>Broken Train</td>
<td>1</td>
<td>47,700</td>
<td>4</td>
<td>39,994</td>
<td>1</td>
<td>81,115</td>
</tr>
<tr>
<td>R.R. Crossing</td>
<td>3</td>
<td>429,033</td>
<td>2</td>
<td>8,726</td>
<td>1</td>
<td>659,700</td>
</tr>
<tr>
<td>Obstruction</td>
<td>7</td>
<td>215,590</td>
<td>4</td>
<td>22,760</td>
<td>4</td>
<td>85,516</td>
</tr>
<tr>
<td>Total</td>
<td>5,778,371</td>
<td></td>
<td>4,473,229</td>
<td></td>
<td>15,168,074</td>
<td></td>
</tr>
</tbody>
</table>

*Compiled by BBN from FRA accident tape.
the trend is real rather than the result of too small a sample size, although the reason for this increase is unknown. For this analysis, we will use only the 1977 total accident cost of $15,168,074, rather than an average figure, remembering the nonconservative nature of this assumption when we consider the results.

### 4.4.3 Indirect costs

The costs shown in Table 11 are only the direct costs of accidents reported to the FRA, including equipment, track, and signal damage. Railroads experience a larger real cost when clean-up costs, lading damage, and claim handling costs, are included. Figures from the St. Paul and Pacific Railroad Company [14] for 40 train accidents caused by freight car equipment failures in 1970 give a sense of the ratio of real costs to FRA-reported accidents costs:

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Accidents</th>
<th>Percent Increase (%)</th>
<th>Total Damage ($)</th>
<th>Average Damage ($)</th>
<th>Damage/Train Miles ($)</th>
<th>Accident/Train Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>2,174</td>
<td>6.5</td>
<td>18,352,058</td>
<td>6,663</td>
<td>20,938</td>
<td>2.48</td>
</tr>
<tr>
<td>1969</td>
<td>2,339</td>
<td></td>
<td>23,056,964</td>
<td>25,288</td>
<td>26,683</td>
<td>1.01</td>
</tr>
<tr>
<td>1970</td>
<td>2,191</td>
<td></td>
<td>19,032,384</td>
<td>8,587</td>
<td>23,693</td>
<td>1.21</td>
</tr>
<tr>
<td>1971</td>
<td>1,912</td>
<td></td>
<td>15,732,800</td>
<td>8,288</td>
<td>20,071</td>
<td>1.24</td>
</tr>
<tr>
<td>1972</td>
<td>1,853</td>
<td></td>
<td>15,224,095</td>
<td>8,270</td>
<td>19,611</td>
<td>1.03</td>
</tr>
<tr>
<td>1973</td>
<td>2,282</td>
<td></td>
<td>27,553,258</td>
<td>11,963</td>
<td>32,782</td>
<td>1.44</td>
</tr>
<tr>
<td>1974</td>
<td>2,238</td>
<td></td>
<td>29,060,242</td>
<td>12,985</td>
<td>34,875</td>
<td>1.72</td>
</tr>
<tr>
<td>1975</td>
<td>1,847</td>
<td></td>
<td>29,971,487</td>
<td>16,211</td>
<td>39,696</td>
<td>2.25</td>
</tr>
<tr>
<td>1976</td>
<td>2,360</td>
<td>6.5</td>
<td>31,999,411</td>
<td>13,534</td>
<td>41,223</td>
<td>1.95</td>
</tr>
<tr>
<td>1977</td>
<td>2,559</td>
<td>106</td>
<td>65,679,391</td>
<td>25,666</td>
<td>87,568</td>
<td>3.41</td>
</tr>
</tbody>
</table>

### Table 12. Train Accidents by Contributing Cause Showing Damage Trends, Class I and Class II Railroads [13]

<table>
<thead>
<tr>
<th>Contributing Cause and Year</th>
<th>Total Accidents</th>
<th>Percent Increase (%)</th>
<th>Total Damage ($)</th>
<th>Average Damage ($)</th>
<th>Damage/Train Miles ($)</th>
<th>Accident/Train Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUMAN FACTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>2,174</td>
<td></td>
<td>18,352,058</td>
<td>6,663</td>
<td>20,938</td>
<td>2.48</td>
</tr>
<tr>
<td>1969</td>
<td>2,339</td>
<td></td>
<td>23,056,964</td>
<td>9,857</td>
<td>26,683</td>
<td>2.21</td>
</tr>
<tr>
<td>1970</td>
<td>2,191</td>
<td></td>
<td>19,032,384</td>
<td>8,587</td>
<td>23,693</td>
<td>1.21</td>
</tr>
<tr>
<td>1971</td>
<td>1,912</td>
<td></td>
<td>15,732,800</td>
<td>8,288</td>
<td>20,071</td>
<td>1.24</td>
</tr>
<tr>
<td>1972</td>
<td>1,853</td>
<td></td>
<td>15,224,095</td>
<td>8,270</td>
<td>19,611</td>
<td>1.03</td>
</tr>
<tr>
<td>1973</td>
<td>2,282</td>
<td></td>
<td>27,553,258</td>
<td>11,963</td>
<td>32,782</td>
<td>1.44</td>
</tr>
<tr>
<td>1974</td>
<td>2,238</td>
<td></td>
<td>29,060,242</td>
<td>12,985</td>
<td>34,875</td>
<td>1.72</td>
</tr>
<tr>
<td>1975</td>
<td>1,847</td>
<td></td>
<td>29,971,487</td>
<td>16,211</td>
<td>39,696</td>
<td>2.25</td>
</tr>
<tr>
<td>1976</td>
<td>2,360</td>
<td></td>
<td>31,999,411</td>
<td>13,534</td>
<td>41,223</td>
<td>1.95</td>
</tr>
<tr>
<td>1977</td>
<td>2,559</td>
<td></td>
<td>35,689,391</td>
<td>25,666</td>
<td>87,568</td>
<td>3.41</td>
</tr>
</tbody>
</table>

---
Costs:
- Damage to roadway and equipment: $590,000
  (direct cost)
- Freight claims paid on fragile: $210,000
  (indirect cost)
- Cost of clearing wrecks: $201,000
  (indirect cost)
Total: $1,021,000

These statistics indicate that the total costs are 1.73 times the equipment and roadway damage costs. A more recent estimate by Southern Railway indicates this ratio to be approximately 2 [16]. Using the figure of 2 and extrapolating to the whole industry, the yearly accident railroad costs are approximately $30,500,000 (2 x 15.2 million direct costs per year) resulting from the mentioned cause codes.

4.4.4 Fatalities and injuries

The number of fatalities and injuries for the identified cause codes, along with the total number of train accident fatalities and injuries for the years 1975 to 1977, are shown in Table 13.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatal Causes</th>
<th>% of Total</th>
<th>Total</th>
<th>Identified Cause Codes</th>
<th>% of Total</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>2</td>
<td>2.4</td>
<td>82</td>
<td>6</td>
<td>4</td>
<td>152</td>
</tr>
<tr>
<td>1976</td>
<td>106</td>
<td>8.7</td>
<td>1,720</td>
<td>75</td>
<td>59</td>
<td>1,279</td>
</tr>
<tr>
<td>1977</td>
<td>2</td>
<td>1.6</td>
<td>1,350</td>
<td>108</td>
<td>114</td>
<td>985</td>
</tr>
</tbody>
</table>

Table 14 lists the total number of injuries and fatalities for all accidents in the railroad industry, including train accidents, train incidents, and nontrain accidents.*

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>1,560</td>
<td>54,306</td>
</tr>
<tr>
<td>1976</td>
<td>1,630</td>
<td>65,331</td>
</tr>
<tr>
<td>1977</td>
<td>1,530</td>
<td>67,867</td>
</tr>
</tbody>
</table>

The injuries and fatalities related to the identified cause codes are a small percentage of the injury and fatality figures for all train accidents and are an even smaller percentage of the indus­trywide accident figures. The numbers are so small that it would be unreason­able to expect a reduction in insurance costs or liability claims from shorter stopping distances. While any number of injuries and fatalities is important from a safety aspect, we do not consider a reduction in these accident figures in this analysis.

4.4.5 Cost savings

With the total accident cost figure, one must develop a sense of what portion of the total savings can be achieved by improving the performance of the train braking system, resulting in shorter stopping distances.

Figure 18, which shows a graph of total accident cost versus a normalized stopping distance, provides insight into the problem. Normalized stopping distance is defined as the ratio of the new stop distance over the baseline stop distance. With the freight train brake system in its present form, $D/D_0 = 1$, the yearly accident costs are $30.5$ million, Point A. If trains could stop almost instantaneously, $D/D_0 = 0$, Point B. The value of Point B is undetermined. There is a function between Point A and Point B that would reflect the details of

Footnote cont’d.

$1,750, and in 1977 to $2,300. The reporting threshold is reviewed periodic­ally and adjusted every two years as necessary.

A Train Incident is an event arising in connection with the movement of railroad on-track equipment which results in a reportable death, injury or illness, but does not result in damage to railroad equipment, track or roadbed of more than $2,300.

A Nontrain Incident is an event which results in a reportable death, injury or illness arising from the operation of a railroad, but not from the movement of railroad on-track equipment.
Figure 18. Accident costs versus normalized stop distance. \( D_0 \) is the baseline stop distance. \( D \) is the new stop distance.

Actual accident occurrence. Developing the exact details of this function would require more detailed accident data than are available. A simple, but not unreasonable, assumption is that the function is linear. Figure 19 is a plot of accident costs versus accident speed for years 1976 and 1977. A least-squares curve fit gives exponents of speed of 0.98 and 1.17, indicating a roughly linear relationship between speed and accident cost. A shorter stopping distance would result in a lower impact speed. This finding qualitatively reinforces the previous assumption of a linear relationship between accident cost and stopping distance.

Figure 19. Accident cost versus speed for 1976 and 1977. Speed compiled from Table 161-A of Refs. 13 and 16.

Data are also not available to determine the location of Point B. Consider the assumption that Point B occurs at the origin instead of at a finite value. As seen in Figure 18, this assumption would give a liberal estimate of the cost savings. As in Sec. 4.2.2, this liberal assumption should be kept in mind in the final consideration of systems or components.

This final assumption reduces the cost of accident saving to the conveniently usable form:

\[
\text{Savings} = (1 - D/D_0) \times \$30.5 \times 10^6.
\]

4.4.6 Summary

We use a normalized stop distance when we compute accident cost savings resulting from decreased stopping distance. The areas of cost saving considered are:

1. Direct cost, equipment, track, and signal damage
2. Lading damage, clean-up costs, claim handling costs

Savings are calculated by using the formula:

\[
\text{Savings} = (1 - D/D_0) \times \$30.5 \times 10^6.
\]

4.5 Derailment During Emergency Stopping

Derailment can occur during emergency stopping because lateral forces generated by car run-in cause rail rollover or wheel climb.

FRA Cause Code 701 "Emergency Brake Application to Avoid Accident" [22] applies to this derailment problem. Table 15 shows the casualties and costs associated with this type of accident.

<table>
<thead>
<tr>
<th>Year</th>
<th>1975</th>
<th>1976</th>
<th>1977</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Accidents</td>
<td>18</td>
<td>17</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>No. of Injuries</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td>No. of Fatalities</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Total Dollar Value</td>
<td>$566,857</td>
<td>$719,325</td>
<td>$280,346</td>
<td>$522,176</td>
</tr>
<tr>
<td>Adjusted Dollar Value* (N $)</td>
<td>1.1</td>
<td>1.4</td>
<td>0.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Twice the reported dollar value to account for unreported clean-up and lading damage costs (see Sec. 4.1).

The data in Table 15 indicate that costs associated with emergency brake application to avoid accidents are sufficiently small to be neglected.
4.6 Coupler and Draft Gear Failure

When trains operate over the road, and when cars are classified in yards, longitudinal dynamic forces are generated that contribute to the failure of couplers and draft gear. During road operations, forces occur as trains start, when they stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made.

In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made. In yards, dynamic forces of up to one million pounds can be created when cars stretch and bunch while traveling over undulating terrain, and when service or emergency brake applications are made.

To determine how improved braking and coupling systems are likely to affect coupler and draft gear failure, it is necessary first to consider the dominant mechanisms of failure. Figure 20 illustrates the problem qualitatively. Extremely high loads could exceed the ultimate strength of the coupler material and cause immediate failure. Moderate loads contribute to fatigue damage, and small loads that are below the endurance limit of the coupler contribute to no damage at all.

The force histogram shown in Figure 20 is not known quantitatively, but some insight into the order of magnitude of the force distributions may be developed from existing data. First, the number of annual load cycles (estimated for 1980)

![Figure 20. Hypothetical Load Distribution and Fatigue Curves for Couplers Illustrating Potential Failure and Fatigue Damage Regimes.](image)

From yard impacts alone is about 200.* One would expect at least that number of in-train load cycles. Moreover, car repair billing data [17] show that approximately 136,000 broken couplers are found annually. For a 1.7 million car population, this corresponds to one failure per year for every 25 cars. Accordingly, the chance that a car would encounter a force large enough to cause an immediate failure must be considerably less than one in 5000. With more than 99.98% of the load cycles occurring below the ultimate strength of the coupler, one must conclude that fatigue is the most probable failure mechanism.

If fatigue failure is the dominant mechanism, one would expect the failure rate (i.e., the probability of failure within a given year) to be low during the initial portion of a coupler's life cycle and to increase sharply toward the end. Figure 21 shows that this is indeed what happens. The failure data presented in Figure 21 are for E60 couplers, and are based on samples of coupler failure and population acquired under the AAR-HPI Railroad Coupler Safety Research and Test Project [17-19].†

The goal of the remainder of this subsection is to estimate the costs associated with coupler and draft gear failures and, more importantly, the financial benefits that could accrue from their reduction.

4.6.1 Fatigue failure analysis

Several major effects occur when the dynamic coupler forces that occur during any segment of a freight car's life cycle are lowered. First, the fatigue damage associated with these forces is reduced and the fatigue lives of key components, such as couplers, knuckles, and yokes, are extended. In turn, the rate of failure for these components is reduced for

*Estimated from Table 6 of this report: 915,000 cars switched daily x 365 days per year/1,655,000 cars in the national fleet.

†The data in Figure 21 were determined as follows. Table 6A of Ref. 18 provides the number of failures versus year of manufacture for 926 samples of failed E60 couplers. Tables 8-11 of Ref. 17 show that 14,939 E60 couplers were reported as broken (why made Code 2) in the Car Repair Billing system which represents about 1/6 of total failures. Accordingly, the sampled data may be scaled up by 14,939 x 6/926 = 96.8 to estimate the total number of failed E couplers by age for the 1972 investigatory period. Similarly, Table 2 of Ref. 19 provides data on the number of E60 couplers versus year of manufacture for a field sample of 5053 couplers. These data are scaled to the entire freight car population by the factor 1,716,937 x 2/5053 = 679.6 where the first number is the 1972 population of freight cars [6] and the 2 accounts for the fact that each car has 2 couplers. The E60 failure rate for the entire population is then computed by dividing the scaled failure data by the scaled population data.
all stages of their life cycles. For example, couplers fail through a fatigue mechanism because of dynamic loads generated in yard impacts and during over-the-road operation. If over-the-road dynamic loads could be eliminated or reduced to levels under the endurance limit, couplers would no longer fail over the road, but would still fail in yards. However, yard failures would occur at a reduced rate because it would take longer to accumulate sufficient fatigue damage through yard impacts alone.

To estimate the decreased overall – or total – failure rate resulting from a decrease in in-train forces, consider the representative fatigue (S-N) curve sketched in Figure 22. As a first approximation, assume that yard impacts generate \( n_Y \) load cycles at a stress level \( S_Y \) and in-train forces occurring in road operations generate \( n_R \) load cycles at stress level \( S_R \). Failure occurs when

\[
\frac{n_Y}{N_Y} + \frac{n_R}{N_R} = 1.
\]

If the in-train forces are reduced with a corresponding reduction in stress from \( S_R \) to \( S_R' \), the coupler materials will be able to absorb more load cycles in yards and over the road before failure occurs. Thus,

\[
\frac{n_Y}{N_Y} + \frac{n_R'}{N_R} = 1.
\]

where the prime designates the number of cycles that occur when the road stress level is reduced. Changing the stress level does not change the loading cycles, which are dictated by operational procedures. Accordingly,

\[
\frac{n_Y}{n_R} = \frac{n_Y'}{n_R'}.
\]

The portion of the fatigue curve shown in Fig. 22 above the endurance limit is described by \( S'^N = B \), where \( a \) and \( B \) are empirically determined constants. Thus,

\[
S_Y^{aN_Y} = B \quad \text{(13)}
\]
\[
S_R^{aN_R} = B \quad \text{(14)}
\]
\[
S_R^{aN_R'} = B \quad \text{(15)}
\]

Fatigue life is proportional to the number of cycles to failure, and the failure rate \( F \) is inversely proportional to fatigue life. Therefore, the ratio of total failure rates \( F_T \) at reduced stress level for in-train forces (yard forces remain constant) to total failure rates \( F_T \) for baseline conditions is

\[
\frac{F_T'}{F_T} = \frac{n_R}{n_R} = \frac{n_Y}{n_Y'}.
\]

From Eqs. 10–16 one obtains

\[
\frac{F_T'}{F_T} = \frac{n_Y}{N_Y} + \frac{n_R}{N_R} \left( \frac{S_Y^{aN_Y}}{S_R^{aN_R}} \right)^{1/2}.
\]

To evaluate the parameters \( n_Y/N_Y \) and \( n_R/N_R \), consider the cumulative damage plot of Figure 23. The figure illustrates graphically the accumulation of damage for each yard impact, \( (Y) \), and each load cycle occurring in road operations \( (R) \). Failure occurs when the sum of all of the

FIGURE 21. FAILURE RATE FOR E60 COUPLERS AS A FUNCTION OF COUPLER AGE.
damage increments reaches unity. The probability $P_R$ that failure occurs during road operations is equal to the probability that an $R$ increment falls on the dashed line. This is simply equal to the total damage of all $R$ increments. Thus,

$$P_R = \frac{n_R}{N_R}. \quad (18)$$

Similarly, the probability $P_Y$ that failure occurs in a yard is

$$P_Y = \frac{n_Y}{N_Y}. \quad (19)$$

Thus,

$$F'_T \over F_T = P_Y + P_R \left( \frac{S'_R}{S_R} \right)^\alpha. \quad (20)$$

The value of the exponent $\alpha$ may be determined experimentally for the particular steel under consideration. Figure 24 shows such experimental data for grades B, C, and E steels used in the manufacture of railroad couplers [20]. As may be seen, the data fall on a nearly straight line on a log-log plot as one would expect from the equation $S^\alpha N = B$ (i.e., $\alpha \log S = \log B - \log N$). Values of $\alpha$ for these data range from 5.1 to 8.5.

The rate of road failures $F_R$ is the total failure rate multiplied by the probability $P_R$ of road failure:

$$F_R = F_T P_R. \quad (21)$$

The ratio of road failure rate $F'_R$ of couplers and draft gear on a train equipped with a candidate braking and coupling system to the rate $F_R$ for a baseline system is given by

$$\frac{F'_R}{F_R} = \frac{F'_T P'_R}{F_T P_R}. \quad (22)$$

Since $F'_T / F_T = n'_R / n_R$, Eqs. 18 and 22 become

$$\frac{F'_R}{F_R} = \frac{n'_R}{n_R} \left( \frac{S'_R}{S_R} \right)^\alpha. \quad (23)$$

Equations 20 and 23 are plotted in Figure 25 to illustrate the dependence of failure rate on stress level. Both curves are for $\alpha = 5.1$, corresponding to Grade E steel. As stresses are reduced below present levels, the road failure rate drops quickly because of the exponential dependence of $F_R$ on the stress ratio.

However, the total failure rate levels off at the 80% level because the major contribution to damage occurs in yards. If the stress level increases beyond present levels, road failure rates will increase quickly, followed by total

*In addition, several thousand cracked knuckles, couplers, and yokes were detected and changed out before a complete break occurred.
failure rates, in which road failures will play an increasingly important part. In summary, it appears that there is considerable risk in increasing intra-car forces, while the benefits of decreasing these forces will accrue mainly in noticeably decreased road failures but only in a fractional decrease in yard failures.

FIGURE 25. FAILURE RATE VERSUS STRESS RATIOS FOR $\alpha = 5.1$.

4.6.2 Train delay costs

As indicated in Figure 15, the two essential inputs to an evaluation of train delay costs are (1) an estimate of the present number of road failures caused by broken draft gear components and the time lost for each failure, and (2) an estimate of the cost per hour of train delay. We shall consider each in detail.

Table 16 shows the distribution of failed components and associated delay times. The data for summer and winter periods suggest that nearly all of the components in the unknown delay category for the summer actually contributed to less than 15 min of delay. Undoubtedly the vast majority were failures detected in yard inspections that did not cause any significant train delay. Accordingly, only the 248 component failures known to cause more than 15 min of delay are considered further.

<table>
<thead>
<tr>
<th>No. of Failures</th>
<th>Summer Period</th>
<th>Winter Period</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 15</td>
<td>155</td>
<td>1567</td>
<td>1722</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>78</td>
<td>170</td>
<td>248</td>
</tr>
<tr>
<td>Unknown</td>
<td>2217</td>
<td>96</td>
<td>2313</td>
</tr>
</tbody>
</table>

A disaggregation of these failures is illustrated in Table 17, which shows mean delay times. The knuckles, which are easiest to change, delay trains less than failed couplers or yokes. Also, as one might expect, delays are longer in the winter when it is more difficult to work on trains.

The data in Table 17 may be used to estimate national train delays in two steps. First, the sample size as a percentage of coupler failures in the national railroad system is estimated. Second, this information is used to estimate the total delays.

<table>
<thead>
<tr>
<th></th>
<th>Summer Period (10 Wks)</th>
<th>Winter Period (4 Wks)</th>
<th>Total (14 Wks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couplers</td>
<td>23</td>
<td>66.4</td>
<td>95</td>
</tr>
<tr>
<td>Knuckles</td>
<td>44</td>
<td>51.5</td>
<td>55</td>
</tr>
<tr>
<td>Yokes</td>
<td>11</td>
<td>58.5</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>78</td>
<td>56.9</td>
<td>170</td>
</tr>
</tbody>
</table>

*Failures that delay trains less than 15 min or unknown delays are ignored.

To estimate the portion of the total population actually represented in Table 17, we use the AAR Car Repair Billing (CRB) data for broken, missing, and bent
couplers* for comparable periods. Table 18 shows these data for summer and winter quarters along with the number of coupler body failures obtained in a 5-railroad sample. Since no data were readily available for the summer of 1971, we used CRB data for the summer of 1972 and assumed there is little difference between one year and the next. In extrapolating the number reported to the total for the quarter, we used a factor of 6 for the AAR-CRB data and the ratio of 13 (the number of weeks in a quarter) to 10 or 4 (the number of weeks during which components were collected) for the RPI/AAR data. The value of 5 was chosen because (1) about one-third of foreign car repairs were billed through the CRB system in 1971 and 1972 and (2) about half of the cars on a railroad at any time are foreign cars. The final column in Table 18 shows that the RPI/AAR team collected a significantly larger portion of the total failed couplers in the winter period than in the previous summer period. Each of the winter and summer data samples represents several percent of the national total.

Table 19 shows the development of estimated train hours of delay per quarter. Column 1, taken from Table 17, is the number of delays identified on the participating railroads. These delays are extrapolated to the quarter in which they occur and then to the national total by using the results of Table 18. Multiplying by the average delay per occurrence (also taken from Table 17) gives the resulting train hours of delay for summer and winter quarters. Adding these figures and multiplying by 2 to obtain the total annual delay gives 32,773 train hours.

**Southern Railway Study.** In 1972, Southern Railway [15] determined road-train delays associated with various modes of draft gear failure for a 7½-month period. As shown in Table 20, most of the delays were attributable to knuckle and coupler failures. These delays may be extrapolated to the national total by

<table>
<thead>
<tr>
<th>Period</th>
<th>Component</th>
<th>(1) No. of Reported Delays</th>
<th>(2) Estimated No. Per Quarter*</th>
<th>(3) Estimated National Total†</th>
<th>(4) Average Train Delay (min)</th>
<th>(5) Total Train Delay Per Quarter (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Coupler</td>
<td>23</td>
<td>29.9</td>
<td>1186.5</td>
<td>66.4</td>
<td>1,313.1</td>
</tr>
<tr>
<td></td>
<td>Knuckle</td>
<td>44</td>
<td>57.2</td>
<td>2269.8</td>
<td>51.5</td>
<td>1,948.3</td>
</tr>
<tr>
<td></td>
<td>Yoke</td>
<td>11</td>
<td>14.3</td>
<td>567.5</td>
<td>58.5</td>
<td>553.3</td>
</tr>
<tr>
<td>Winter</td>
<td>Coupler</td>
<td>95</td>
<td>308.8</td>
<td>5454.9</td>
<td>83.4</td>
<td>7,582.4</td>
</tr>
<tr>
<td></td>
<td>Knuckle</td>
<td>55</td>
<td>178.8</td>
<td>3158.1</td>
<td>62.1</td>
<td>3,268.7</td>
</tr>
<tr>
<td></td>
<td>Yoke</td>
<td>20</td>
<td>65.0</td>
<td>1148.4</td>
<td>89.9</td>
<td>1,720.7</td>
</tr>
</tbody>
</table>

*Multiply column 1 by 13/10 for summer and 13/4 for winter periods.
†Divide column 2 by 0.0252 for summer and 0.0566 for winter periods. (see Table 18).

*Why-made Codes 02, 03, 05, and 06 for AAR Interchange Rules 16, 17, and 18 [21].
TABLE 20. ROAD-TRAIN DELAYS CAUSED BY VARIOUS COMPONENT FAILURES DURING A 7%-MONTH PERIOD ON THE SOUTHERN RAILWAY [15].

<table>
<thead>
<tr>
<th>Component</th>
<th>No.</th>
<th>Average Delay Per Failure (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knuckle</td>
<td>270</td>
<td>1.2</td>
</tr>
<tr>
<td>Coupler</td>
<td>213</td>
<td>2.05</td>
</tr>
<tr>
<td>Yoke</td>
<td>10</td>
<td>3.0</td>
</tr>
<tr>
<td>Key</td>
<td>10</td>
<td>2.7</td>
</tr>
<tr>
<td>Carrier</td>
<td>8</td>
<td>2.5</td>
</tr>
<tr>
<td>Follower Stops</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td>End Sill</td>
<td>7</td>
<td>2.25</td>
</tr>
<tr>
<td>Center Sill</td>
<td>5</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>524</td>
<td>1.66</td>
</tr>
</tbody>
</table>

\[ D_T = (524)(1.66) \frac{12}{7.5} T_{M_n} \tag{24} \]

where the ratio 12/7.5 scales the data to a full year, \( T_{M_n} = 858 \times 10^9 \) is the national revenue ton miles for 1978 [5], and \( T_{M_S} = 44 \times 10^9 \) is the revenue ton miles for the Southern Railway in 1972 [22]. Thus,

\[ D_T = 27,139 \text{ train hr.} \]

**MIT Study of Penn Central.** In September and October of 1969, MIT researchers investigated delays on a section of the Penn Central connecting Framingham, MA with Selkirk, NY [22]. The investigation was carried out by reviewing train crew "morning reports" describing the cause of delays. The team found that 34 coupler mechanical failures (and 8 slipping knuckles) occurred during 152,000 train miles of operation. The average delay for both types of coupler failure is 76 min.* Extrapolating these data to the national average gives

\[ D_T = 34 \times 76 \times \frac{432,944}{152} = 122,667 \text{ train hr}, \tag{25} \]

where 432,944 is the number of freight train miles operated by Class I railroads in the U.S. in 1978 [5].

**Summary of Train Delay Times and Costs.** The train delay times obtained from the three independent sources discussed above are summarized as follows:

<table>
<thead>
<tr>
<th>Source</th>
<th>Estimated Total Delay (Train Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPI/AAR Coupler Project [18]</td>
<td>32,773</td>
</tr>
<tr>
<td>Southern Railway [15]</td>
<td>27,139</td>
</tr>
<tr>
<td>MIT Study of Penn Central [22]</td>
<td>122,667</td>
</tr>
</tbody>
</table>

The results for RPI and Southern data are quite consistent, while the MIT/Penn Central results are high, as one might expect. These latter data were obtained for a section of track that had several heavy grades (up to 1.67%), which resulted in large coupler forces and increased the likelihood of failure. Moreover, the data were collected in 1969, just before the Penn Central bankruptcy, when the physical condition of equipment was undoubtedly below the national average.

One would expect the RPI delay figures, which are based on data from five major railroads, to be somewhat more representative of the national situation and also to be higher than those for the Southern Railway. Southern has been operating newer cars (more than half are less than 10 years old [22]), which are less likely to fail. Accordingly, for further calculations we use the RPI/AAR Coupler Project data as a baseline.

**Hourly Cost of Train Delay**

We have estimated the cost of train delay time to be \$185.82/hr. This figure was derived by using a consensus costing approach developed from an examination of costing methodologies used by a number of Class I railroads.†

In this section, we outline these costing methodologies and cost train delay time, using the consensus approach, and point out the sensitivity of the consensus cost to inconsistencies in methodologies among the railroads studied.

Table 21 outlines costing methodologies. The table lists cost elements (those items actually costed) and costing variables (the methods and assumptions used for costing) for each railroad (Columns A, B, and C), and a consensus methodology (Column D).

The following are the major cost elements:

- Time cost of equipment accounts for the expense of ownership or unproductive equipment (during train delay, locomotives and cars do not produce revenue).

† Railroads that provided information for this study requested that their names not be divulged.
### TABLE 21. COSTING METHODOLOGIES FOR TRAIN DELAY TIME.

<table>
<thead>
<tr>
<th>Included in Costing Methodology</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost Elements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Cost of Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locomotives</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Freight Cars</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Freight Cars Per Diem</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Fuel Expense</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Cost of Crew Time</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Maintenance Costs</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Costing Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valuation Methodology for Cost of Equipment</td>
<td>DCF*</td>
<td>DCF</td>
<td>DCF</td>
<td>DCF</td>
</tr>
<tr>
<td>Internal Rate of Return (%)</td>
<td>20</td>
<td>20</td>
<td>N/A</td>
<td>20</td>
</tr>
<tr>
<td>Hours in Train Year</td>
<td>8760</td>
<td>5840</td>
<td>8760</td>
<td>8760</td>
</tr>
</tbody>
</table>

*Discounted Cash Flow.

Costing variables are as follows:

- The valuation methodology for cost of equipment used by all firms is the discounted cash flow technique.
- The internal rate of return used by those firms that offered information is 20 percent.
- Hours in a train year used for costing methodologies vary among railroads. Firms A and C view railroad operations as a 24-hr/day, 365-day/yr business, or an 8,760-hr year. Firm B considers a 16-hr/day and a 365-day/yr, or a 5,840-hr year.

The following develops the cost of train delay time for the consensus methodology shown in Column D, Table 21.

Our costing procedure assumes a typical train consisting of:

- 68 cars (67 freight cars†† and 1 caboose)
- 3 locomotives‡
- 4-man crew.†

The elements to be costed are:

- Locomotive
- Cars
- Fuel
- Crew time
- Maintenance.

**Locomotive costs:**

- Locomotive, original costs, $650,000‡‡

---

*Firm C did not reveal the ratio of owned to foreign cars that it considers in an average train.

†According to the National Railway Labor Conference, crew earnings are based on a number of variables including: hours worked, mileage, tonnage hauled, and number of car blocks in the train. Depending on lengths of runs, for example, some railroads pay crew on an hourly basis (those with runs under 100 miles), whereas others (those with runs over 100 miles) pay on a mileage basis. (Personal Communication with Mr. Roberts of the NRLC on 16 October 1978.)

**It can be argued that freight cars accrue some maintenance expense solely on the basis of age (e.g., repair and replacement of weathered parts). Also, idling locomotives accrue maintenance expense because of engine wear. For these reasons, we include maintenance costs in the consensus methodology.

††The 1979 AAR Yearbook of Railroad Facts shows 67.1 freight cars in the average train [5].

‡From discussion with railroads.

‡‡FRA estimate for typical road haul locomotive.
• 15-year lifetime. *
• With a 20 percent internal rate of return and an 8,760-hr train year, the required yearly return from this investment is $139,186, or $15.89/hr.†

Freight Car Costs:
• Freight cars, original cost, $33,818** 30-year lifetime [34].
• With a 20 percent internal rate of return and an 8,760-hr train year, the required yearly return from this investment is $6,791, or 0.78/hr.†

Fuel Costs:
• Locomotives burn five gallons of diesel fuel per hour while idling. The cost for diesel fuel is $0.659/gal. ‡‡ Therefore, the fuel cost per hour idle time for a locomotive is $3.30.

Crew Time:
• The average compensation (including health and welfare benefits and payroll taxes) per crew member is as follows:
  
  | Average Annual Earnings (train and engine service) | $24,025 |
  | Payroll Taxes* | 3,685 |
  | Health and Welfare and Pensions* | 1,742 |
  | Hourly cost per crew member: | $14.16 |

*Train and engine service crew payroll represents 35.4% of total payroll. Total health and welfare and pension expenses were $695 million, and payroll taxes were $1,470 million [6]. Taking 35.4% of these values and dividing by 141,220 train and engine service employees gives the above results.

†Calculation is made by discounting a stream of equal cash flows over the lifetime of the asset.
‡‡AAR average cost for "freight carrying cars" as of July 1978.

The only railroad that provides this information uses a 15-year locomotive lifetime for its calculations.

Maintenance Costs:
• The average per-hour cost for diesel locomotive maintenance is $4.83. The average per-hour cost for freight car maintenance is $0.12.†

Total Costs (Consensus Methodology)

| Locomotives: | $47.67 |
| Freight Cars: | 53.04 |
| Fuel: | 9.90 |
| Crew: | 56.64 |
| Maintenance: | 14.49 |
| Total | 185.82 |

Sensitivity of Consensus Cost to Inconsistencies in Methodologies Among Reporting Railroads

The railroads we studied differed in their handling of the following cost elements and costing variables:
• Time cost of equipment
• Cost of crew time
• Maintenance costs
• Hours in train year.

Time Cost of Equipment. This inconsistency involves the consideration of owned cars only versus a combination of owned and foreign cars in a train. (The railroad that considers a combination did not state the proportion of each in a typical train.)

The per diem rate for a new $33,000 to $35,000 freight car is $11.78, or $0.49/hr, for a 24-hr day. We determined the cost of ownership per hour for an equivalent freight car to be $0.78. Thus, the effect of using per diem costs rather than ownership costs lowers the cost of train delay time. The amount of cost reduction depends on the ratio of foreign to owned cars assumed in the train and the age and original cost of the foreign cars. ‡‡

Assume a one-to-one ratio of owned to foreign cars and per diem rates for a new $33,000 to $35,000 car.

†Includes a 10 percent increase (to account for inflation) above 1977 AAR maintenance cost statistics. An 8,760-hr/year is used for calculation.
‡‡AAR car hire rate, ICC Docket No. 33145.
Per diem costs are calculated on the basis of age and original cost. The higher the original cost and the younger the car, the higher the per diem rate.
The cost for a 68-freight-car train would be:

Owned: 34 cars × $0.78/car/hr = $26.52/hr
Foreign: 34 cars × $0.49/car/hr = $16.66/hr
Total = $43.18/hr

This total is $9.86/hr less than the $53.04 total previously calculated for all owned cars.

Cost of Crew Time. This inconsistency involves the inclusion or exclusion of labor charges. According to our calculations, the inclusion of crew costs raises the cost of train delay time by $56.64/hr.

Maintenance Costs. This inconsistency involves the inclusion or exclusion of maintenance costs. According to our calculations, the inclusion of these costs raises the cost of train delay time by $18.57/hr.

Hours in Train Year. This inconsistency involves the number of hours railroads include in a train year. The railroads studied used 5,840 and 8,760 hour-years. The use of a 5,840-year versus an 8,760-hr year increases the per-hour cost of equipment ownership and maintenance costs by 50 percent.

Summary

Table 22 summarizes the costs developed for train delay time, using 8,760 and 5,840-hr years.

<table>
<thead>
<tr>
<th>TABLE 22. SUMMARY OF TRAIN DELAY COSTS.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Cost of Equipment</td>
</tr>
<tr>
<td>Locomotives</td>
</tr>
<tr>
<td>Freight car (ownership cost)</td>
</tr>
<tr>
<td>Freight car (ownership cost and per diem)</td>
</tr>
<tr>
<td>Fuel Expenses</td>
</tr>
<tr>
<td>Cost of Crew Time</td>
</tr>
<tr>
<td>Maintenance Costs</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*Assumes 3 locomotives, 68 cars (67 freight cars and 1 caboose), and a 4-man crew.

*We have not included incentive per diem in this calculation, although for designated car types during specific periods of time the incentive per diem will increase the hourly car hire rate.

When the information in Table 22 and the approaches presented in Table 21 are used, the railroads examined would cost train delay as follows:

Railroad A: $167.25/hr
Railroad B: 188.83/hr
Railroad C: 157.39/hr
Consensus D: 185.82/hr

It can be seen that although cost elements and costing variables differ significantly among responding railroads, the range of costs developed for train delay time is relatively narrow, from $157.39/hr to $188.83/hr. Therefore, we used $185.82/hr for our cost calculations. Multiplying the previously calculated 32,773 hours of coupler failure caused train delay by the hourly train cost of $185.82/hr gives

Train Delay Cost = $6 million.

4.6.3 Derailments and broken train collision costs

We analyzed an FRA accident data tape [12] to determine the number and costs of derailments and broken train collisions associated with broken coupler and draft gear. Table 23 shows these data for the 3-year period (1975 to 1977). Although Tables 17 and 20 have shown that there are more line-of-road failures resulting from broken knuckles than any other coupler or draft gear component, Table 23 indicates that most of the derailments are attributable to broken or defective coupler heads. Similarly, there is a disproportionate number of derailments caused by broken or defective draft gear. The probable reason for this imbalance is that couplers and yokes are substantially larger than knuckles and more likely to cause a derailment when they fall to the tracks.

Table 23 shows that broken or defective couplers and knuckles account for the largest number of broken train collisions. However, the costs of these types of accidents are only a small percentage of the derailment costs.

Combining the derailment with broken train collision costs results in about $6 million of reported annual costs associated with coupler failures. As discussed previously, direct costs to the railroads, including cleanup and lading damage claims, are twice the reported costs. Accordingly, we use the following figure in subsequent calculations:

Accident Costs = $12 million.
4.6.4 Maintenance costs

Couplers are repaired or replaced primarily because they crack to a condemnable limit, break, or wear. Cracks and breaks are mainly a fatigue type of failure that results from the cumulative effects of unsteady forces. Particularly large forces are generated during coupling impacts in yards, starting and stopping maneuvers in road operations, and the slack action that accompanies operation over undulating terrain.

Wear occurs as the unlubricated surfaces of adjacent components rub against each other during normal train operation. A good example is the vertical motion between the knuckles of E couplers as cars move over uneven track. Small amounts of material are removed through each cycle until the components reach condemnable limits and are removed from service.

Table 24 shows the estimated annual cost to replace couplers that are broken or worn during normal service. The costs per component were obtained from the Office Manual of the AAR Interchange Rules [26] and apply generally to the least expensive replacement components. Industry impact estimates were obtained by multiplying the component costs by the number of failed components estimated from CRB data obtained by the RPI/AAR coupler safety team [17, 26]. The results suggest that nearly 100 million dollars are spent annually to repair and replace couplers and associated components, most of which result from fatigue-related failures.

As discussed in Sec. 4.6.1, about 20% of knuckle, coupler, and yoke fatigue failure damage is caused by forces developed in road trains and 80% is due to yard impacts. Therefore, of the $62.7 million of broken component costs estimated in Table 24, up to $12.5 million (i.e., 20%) could be saved through decreased in-train forces and $50.2 million through decreased impact forces. It should be recognized, however, that

### Table 23. Derailments and Broken Train Collisions Caused by Coupler Failures [18].

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Cost*</td>
<td>No.</td>
<td>Cost*</td>
<td>No.</td>
<td>Cost*</td>
</tr>
<tr>
<td>430 Knuckle Broken or Defective</td>
<td>39</td>
<td>552</td>
<td>35</td>
<td>652</td>
<td>30</td>
<td>680</td>
</tr>
<tr>
<td>432 Coupler Drawhead Broken or Defective</td>
<td>126</td>
<td>3332</td>
<td>128</td>
<td>3489</td>
<td>94</td>
<td>2114</td>
</tr>
<tr>
<td>434 Draft Gear/Mechanisms Broken or Defective (including yoke)</td>
<td>26</td>
<td>413</td>
<td>46</td>
<td>1036</td>
<td>36</td>
<td>1137</td>
</tr>
<tr>
<td>435 Coupler Carrier Broken or Defective</td>
<td>20</td>
<td>207</td>
<td>17</td>
<td>659</td>
<td>21</td>
<td>661</td>
</tr>
<tr>
<td>436 Coupler Shank Broken or Defective</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>486</td>
</tr>
<tr>
<td>Total Identified Causes:</td>
<td>211</td>
<td>4504</td>
<td>226</td>
<td>5836</td>
<td>194</td>
<td>5078</td>
</tr>
<tr>
<td>439 Cause Code Not Listed</td>
<td>20</td>
<td>492</td>
<td>35</td>
<td>276</td>
<td>38</td>
<td>906</td>
</tr>
<tr>
<td>Total All Causes</td>
<td>231</td>
<td>4996</td>
<td>261</td>
<td>6113</td>
<td>232</td>
<td>5986</td>
</tr>
</tbody>
</table>

*Including locomotives
Costs in thousands of dollars.

### Table 24. Estimated Annual Coupler Replacement Costs.

<table>
<thead>
<tr>
<th>Estimated Cost Per Component* ($)</th>
<th>INDUSTRY IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>Material</td>
</tr>
<tr>
<td>No. (Thous)</td>
<td>Percent ($)</td>
</tr>
<tr>
<td>Couplers</td>
<td>26.43</td>
</tr>
<tr>
<td>Knuckles</td>
<td>3.51</td>
</tr>
<tr>
<td>Yokes</td>
<td>57.88</td>
</tr>
<tr>
<td>Total</td>
<td>579.3</td>
</tr>
</tbody>
</table>
these are upper bound estimates since wear and fatigue are undoubtedly correlated. While couplers are accumulating fatigue damage, they are also undergoing adhesive (and possibly abrasive) wear. Eliminating fatigue would increase coupler lives, but only to the point at which they would be condemned for excessive wear.

4.6.5 Summary

A summary of the first-cut estimates discussed above of costs associated with coupler and draft gear failure is given in Table 25. Table 25 shows that most of the costs are attributable to maintenance and, of these expenditures, most can be traced to coupling impacts in yards.

<table>
<thead>
<tr>
<th>Location</th>
<th>Cause</th>
<th>Annual Cost (Millions of Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>Train delays</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Derailments &amp; collisions</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Coupler, knuckle, &amp; yoke repair &amp; replacement</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>Total Road</td>
<td>30.5</td>
</tr>
<tr>
<td>Yard</td>
<td>Coupler, knuckle, &amp; yoke repair &amp; replacement</td>
<td>50.2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>80.7</td>
</tr>
</tbody>
</table>

4.7 Lading Damage

Lading may be damaged because of excessively high impact forces occurring during switching, longitudinal train action, or vibration associated with rough track. While the contributions of these dynamic stimuli to lading damage are not known quantitatively, it is generally believed that most of the damage results from car-to-car impacts in yards [27].

The railroad industry has been dealing with this problem in a variety of ways. End-of-car or sliding sill cushioning devices are installed on cars to absorb energy and reduce peak loadings. Improved techniques for packaging of fragile commodities have been investigated and utilized. Finally, special handling procedures for cars carrying hazardous or fragile goods are followed. While most of these approaches will not be influenced by the components identified in Sec. 2, the ultrasonic brake control system (Item 9 in Table 1) has the potential to reduce lading damage significantly through controlled car impact.

To estimate the potential savings associated with controlled car impact, we may review the AAR freight loss and damage statistics. The AAR divides loss and damage payments into the following 12 causes [28].

1. Shortage, packaged shipment
2. Shortage, bulk shipment
3. All damage not otherwise provided for
4. Defective or unfit equipment
5. Temperature failures
6. Delay
7. Robbery, theft, pilferage
8. Concealed damage
9. Train accident
10. Fire, marine and catastrophies
11. Error of employees
12. Vandalism.

Of these, only Cause 3 - All damage not otherwise provided for, includes damage due to car impacts. In 1977, Cause 3 alone accounted for $155 million in expenditures (out of a total of $278 million for all 12 causes). However, not all of these Cause 3 losses can be attributed to dynamic effects. By eliminating from consideration such apparently shock-insensitive commodities as those shipped in bulk (coal, grain, minerals), frozen foods, and others, the commodity damages listed in Table 26 are identified as potentially avoidable. On the one hand this figure is an upper limit because it undoubtedly includes some costs that are not shock related. However, the total of $100 million represents only direct payments and does not include the indirect cost of processing these payments or the opportunity cost associated with lost revenue. These costs can be significant.

Twenty years ago, Baillie estimated that in 1958 the $43 million of freight loss and damage payments associated with end of car impacts represented $100 million in real costs [29] which, accounting for the inflated value of direct payments, would correspond to about $233 million of total costs in 1977. In balance, it appears that $100 million is a reasonable estimate of freight damage costs that could actually be eliminated through control of car impact.
<table>
<thead>
<tr>
<th>AAR Code</th>
<th>Commodities</th>
<th>Payment in 1977 (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>012</td>
<td>All Fresh Fruits and Tree Nuts</td>
<td>881,796</td>
</tr>
<tr>
<td>013</td>
<td>All Fresh Vegetables</td>
<td>1,054,708</td>
</tr>
<tr>
<td>2031</td>
<td>Canned or Cured Sea Foods</td>
<td>338,499</td>
</tr>
<tr>
<td>2032</td>
<td>Canned Specialties</td>
<td>112,717</td>
</tr>
<tr>
<td>2033</td>
<td>Canned Fruits or Vegetables</td>
<td>1,657,110</td>
</tr>
<tr>
<td>2035</td>
<td>Pickled Fruits or Vegetables</td>
<td>169,617</td>
</tr>
<tr>
<td>2039</td>
<td>Mixed Shipments of Canned Goods</td>
<td>988,242</td>
</tr>
<tr>
<td>20821</td>
<td>Beer</td>
<td>1,803,907</td>
</tr>
<tr>
<td>2084</td>
<td>Wines, Brandy</td>
<td>340,269</td>
</tr>
<tr>
<td>20851</td>
<td>Whiskey</td>
<td>440,612</td>
</tr>
<tr>
<td>209</td>
<td>Misc. Food Preparations</td>
<td>7,326,757</td>
</tr>
<tr>
<td>2432</td>
<td>Plywood or Veneer</td>
<td>1,098,101</td>
</tr>
<tr>
<td>25</td>
<td>Furniture and Fixtures</td>
<td>2,293,335</td>
</tr>
<tr>
<td>26211</td>
<td>Newsprint</td>
<td>3,339,302</td>
</tr>
<tr>
<td>321</td>
<td>Flat Glass</td>
<td>742,019</td>
</tr>
<tr>
<td>322</td>
<td>Glassware</td>
<td>194,987</td>
</tr>
<tr>
<td>34</td>
<td>Fabricated Metal Products</td>
<td>2,075,750</td>
</tr>
<tr>
<td>35</td>
<td>Machinery Except Electrical</td>
<td>3,310,877</td>
</tr>
<tr>
<td>363</td>
<td>Household Appliances</td>
<td>1,957,621</td>
</tr>
<tr>
<td>3711</td>
<td>Motor Vehicles</td>
<td>66,127,720</td>
</tr>
<tr>
<td>3714</td>
<td>Motor Vehicle Parts</td>
<td>2,864,763</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>99,118,709</strong></td>
</tr>
</tbody>
</table>
5. EQUIPMENT

5.1 Objectives

To evaluate equipment, the methodology develops cost estimates for the components and systems to be used in the financial analysis. Many of the identified components already exist in production or prototype form and can be costed directly; however, no hardware exists for several of the components.

Rough preliminary designs are the first step toward hardware conceptualization for these components. The design gives one possible realization of the component function and allows a reasonable estimate of the required component size, complexity, location, etc. Designs should contain sufficient detail for reasonable costing estimates, but are not intended to be detailed hardware designs.

5.2 Costing

The three areas of costing to be considered are:

- Initial equipment cost
- Initial installation labor cost
- Annual maintenance and replacement cost.

Considerable costing work has been performed in a previous study [2]. We will use similar costing assumptions and methodology to allow the maximum use of the previous work and make the new costs consistent with the earlier ones.

5.2.1 Costing assumptions

The components and systems must be costed with a consistent set of assumptions. The costing assumptions define included and excluded costs and the conditions under which the components and systems are costed. The costing assumptions are:

1. All costs are based on constant 1979 dollars and include an estimate of the total of labor and material costs.
2. Projections of costs assume that full-quantity production would reach a level of at least 50,000 car sets per year.
3. Initial system costs for a new car system are estimated as additional to the cost for the basic car equipped with standard components. If the new system element is not estimated to increase the cost over the basic car system, this estimate is indicated by a NI (No Increase).
4. Initial system costs for modified cars are estimated as an addition to the cost for new standard components.
5. No costs are included for preparation or repair of old cars prior to installation of the new system (or subsystem). It is assumed that all cars to be modified would be in a state of full repair at the time of modification.
6. No cost estimate is included for value of the revenue time lost by each car during the modification program.
7. Annual maintenance and replacements costs are estimated on the basis of the estimated replacement life of each listed equipment item, including estimated replacement labor and upkeep labor.
8. It is assumed that an average of one Interchange Adapter unit would be required for each car with an incompatible coupler system.

5.2.2 Costing methodology

These costing assumptions and the factors listed below will be used to derive the preliminary costs for each component and system.

1. Review of technical literature for past cost estimates.
2. Discussion with railroad industry suppliers and users to verify concept production potentials.
3. Preliminary engineering evaluation of complexity of new concepts as compared with the baseline system.
4. Evaluation of present costing as a function of the complexity of concept design and relative quantities produced.
5. Engineering estimate of potential replacement life of new concepts, as compared with reported field problems with similar systems.
6. INSTITUTIONAL ISSUES

Institutional policy affecting railroad operations must be considered when the potential benefits from the implementation of advanced braking and coupling technology are evaluated. In some cases, institutional policy can limit or even prevent the realization of benefits. In this section, we examine five major institutional policy areas that could directly affect the level of benefits that can be achieved by introducing advanced technology. These are:

- **PRA switching regulations for cars containing hazardous materials**
- **PRA power brake regulations**
- **Safety Appliance Act**
- **Work practice arbitration**
- **Crew consist agreements**

Below, we explain how these issues might change potential benefits.

- **Switching Regulations for Cars Containing Hazardous Materials:** PRA regulations regarding the switching of cars containing hazardous materials can limit the benefits to be realized from improved yard switching resulting from advanced braking and coupling systems.

The Federal Code, CFR 49, Chap. II, Secs. 174.83-174.85 [30], requires that cars placarded "Explosive A" and "Poison Gas" and placarded flat cars prescribed by Part 172 of this subchapter can not be cut off while in motion and that no car moving under its own momentum is permitted to strike these placarded cars. Clearly, any evaluation of advanced systems that could reduce crew size must take into consideration this regulation, which may not permit a reduction of manpower.

- **PRA Power Brake Regulations:** Certain changes in PRA power brake regulations may be required before advanced technology can realize potential benefits. These regulations require the inspection and testing of train brake systems at departure and various intermediate points. For example CFR 49, Chap. II, Sec. 232.12, requires that an inspection of train brakes include an examination of angle cock position, brake application, piston travel, and brake rigging.

Advanced systems capable of monitoring some, but not all, of the brake system components mentioned in the regulation (e.g., a system capable of automatically monitoring all components except brake rigging) can potentially generate savings but only if the regulation is changed. In this example, the regulation could be changed to allow brake rigging inspection before the power brake test.

- **Safety Appliance Act:** This Act, as amended April 1958 (45 USC 9), adopted the AAR rules; standards, and instructions related to power or train brakes as ICC Rules. Subsequently, the Secretary of Transportation has the authority to enforce and modify these rules. Section 9 states in part:

The rules, standards, and instruction of the Association of American Railroads, adopted in 1925 and revised in 1933, 1934, 1941, and 1953, with such revisions as may have been adopted prior to the date of enactment of the Power or Train Brakes Safety Appliance Act of 1958, for the installation, inspection, maintenance, and repair of all power or train brakes for common carriers engaged in interstate commerce by railroad shall remain in force; the rules, standards, and instructions for the installation, inspection, maintenance, and repair of all power or train brakes unless changed, after hearing, by order of the Secretary of Transportation. Provided however, that such rules or standards or instructions or changes therein shall be promulgated solely for the purpose of achieving safety.

Note that the final sentence appears clearly to limit further changes to the regulations to areas concerning safety. Thus, a literal interpretation of the Act would prohibit a change to the regulations proposed solely for the economic benefit of railroads. The advanced monitoring system designed to automate the power brake inspection procedure, described in the previous section, is an example of the kind of technology that would require changes in regulations to yield economic benefits. The existing regulation requiring this inspection could not be changed by the Secretary of Transportation within his authority under 45 USC 9. The potential benefit of the new technology would not be realized without a congressional change to the code.

A literal reading of the safety test, however, may not be proper. The legislative history of this amended code section [31] indicates that the safety test was added only to "make it clear that these rules are for the purpose of safety, and not for the purpose of limiting the length of trains." The railroads had taken a position against the Act, fearful that it would serve to require shorter trains and thus increase the number of train crews.
It can be interpreted, therefore, that the intent of Congress was not to limit changes just to safety but to limit changes unrelated to safety that would have a negative economic impact on railroads. Under this interpretation, a change to the regulations having no safety impact, and a favorable economic impact on the railroads, would fall within the authority of the Secretary of Transportation under this Act.

- **Work Practice Arbitration:** Arbitration regarding the established work practices of the various railroad crafts has the potential to limit or even nullify benefits. The implementation of systems that require employees to cross over traditional job boundaries (e.g., a remote system that allows engineers rather than trainmen to uncouple cars) may meet opposition from craft unions. Union opposition to changes in work practice is likely to become manifest in labor-management arbitration. It is not an easy task for management to win changes in established work practice, and therefore negotiation is likely to result in compromise.

- **Crew Consist Agreements:** Reduction in crew consist, a corollary to the benefits of advanced systems, is also likely to meet opposition from unions. To win concessions from unions on this issue, precedent has shown, management may have to make payments to unions. Such payments have been a part of recent agreements to reduce crew size between the United Transportation Union (UTU) and the Milwaukee Road, Conrail, and the Canadian National (CN). The following is a brief summary of the provisions of UTU's recent agreement [32] with the CN:

  - Operation of freight trains with a train crew of a conductor and one brakeman in all territories where manual flagging to the rear is not required.
  - Creation of a special fund, a savings-sharing fund, for the sole benefit of protected employees, defined as those employees with seniority dates as brakemen on or before August 3 of this year (1971).
  - Full job protection for trainmen hired on or before August 3, along with establishment of a voluntary separation plan.
  - CN's contribution to the special sharing fund will be an amount equal to 25% of savings generated through operation with fewer crew members.

Costs to the American roads have been higher:

The U.S. agreements call for payment of $4 (subject to escalation) to train crew members working on short crews plus a payment of $48.25 into a productivity fund for every trip or tour worked with a reduced crew, and that works out to a significantly higher [than the agreement between UTU and CN] percentage of savings [32].

The financial analysis is sensitive to the potential impact of each of these institutional issues.
7. FINANCIAL ANALYSIS

The financial analysis provides an assessment of the feasibility of implementing those advanced braking and coupling systems identified as potentially beneficial to the railroads. The assessment is made both for individual railroads and for the rail system as a whole.

Central to the generation of these feasibility estimates is a financial model drawn from the operations and mechanical analyses that is sensitive to future scenarios, implementation strategies, and institutional constraints. The model's output—an estimate of the amount available for the implementation of a given system—is then compared with the equivalent hardware and implementation cost estimates from the equipment analysis. This comparison allows a reasonable evaluation of the given system's feasibility.

The basis of the financial model is the net present value (NPV) method of asset valuation. In essence, NPV discounts a stream of future cash flows as follows:

\[ \text{NPV} = \sum_{t=0}^{\infty} \frac{C_t}{(1+P)^t}, \]  

(27)

where \( \text{NPV} \) = the net present value of an investment project, \( C_t \) = the expected after-tax cash flow generated by the project at time \( t \), \( P \) = the appropriate discount rate or "cost of capital." (This rate reflects the return a railroad must earn on a given project in order to generate funds from investors.)

When NPV is set equal to zero, and the equation is solved for \( P \), \( P \) is called the internal rate of return (IRR), a rate which companies often set as a standard for project acceptance.

\[ \sum_{t=0}^{\infty} \frac{C_t}{(1+\text{IRR})^t} = 0. \]  

(28)

The \( C_t \)'s are in essence the yearly net values of system benefits and system costs. When the system benefits can be estimated, an IRR established, an implementation period outlined, and a system lifetime defined, the equation can be solved to determine maximum acceptable system costs. This technique is the heart of the financial model. A single example follows.

Assume:

- System benefits = \$1,000/yr
- Required IRR = 20%
- System is fully implemented at beginning of project, \( t = 0 \)
- System lifetime = 3 yrs

Determine the maximum acceptable cost \( x \) to implement the example system.

\[ -x + \frac{1000}{1.2} + \frac{1000}{(1.2)^2} + \frac{1000}{(1.2)^3} = 0 \]

\[ x = \$2106. \]

In addition to a calculation of maximum acceptable system costs, the model is also designed to calculate investment payback period. Payback period is that specific length of time within which cash investment is recovered. It is calculated by summing cash flows over time to the point at which cumulative cash inflows exactly balance cumulative cash outflows. The example presented in the table below has a payback period of 6 years:

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5-25</th>
<th>26-36</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash Flow</td>
<td>-1000</td>
<td>-1000</td>
<td>+300</td>
<td>+300</td>
<td>+400</td>
<td>+500</td>
<td>0</td>
</tr>
</tbody>
</table>

7.1 Model Inputs

Table 27 outlines the inputs required to calculate the amounts available for implementing advanced systems. Each of the inputs is a model variable.

For financial analysis, benefits, as shown in Table 27 must be separated into those savings that are subject to union payout and those that are not.* Table 28 lists the areas of potential benefit from advanced systems (increased savings net of increased costs) and the data source for each.

Once benefits have been quantified, adjustments must be made to determine the net benefit to the system (or company). Calculation of these adjustments requires the input shown in Table 27. The function of each of these inputs is as follows:

- Material/labor inflation rates are required inputs, as the costs of materials and labor are expected to change over time.

*Union payout refers to paying unions some fraction of the savings which come from the reduction of labor expense (e.g., reduction of crew size).
TABLE 27. REQUIRED FINANCIAL MODEL INPUTS.

<table>
<thead>
<tr>
<th>Benefits*</th>
<th>Adjustments to Benefits</th>
<th>Structural Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Labor savings per year subject to union payout</td>
<td>• Material/labor inflation rates</td>
<td>• Number of cars in system</td>
</tr>
<tr>
<td>• Savings per year not subject to union payout</td>
<td>• Fraction of labor savings paid to union</td>
<td>• Years to system compatibility</td>
</tr>
<tr>
<td></td>
<td>• Number of years of union payout</td>
<td>• Years cash flows to be calculated</td>
</tr>
<tr>
<td></td>
<td>• Depreciation method</td>
<td>• Asset lifetime</td>
</tr>
<tr>
<td></td>
<td>• Fraction of investment allowable for investment tax credit</td>
<td>• Fraction of cars replaced per year</td>
</tr>
<tr>
<td></td>
<td>• Federal tax rate</td>
<td>• Internal rate of return</td>
</tr>
</tbody>
</table>

*These benefits are net of any cost changes resulting from the implementation of advanced systems.

TABLE 28. SYSTEM BENEFITS.

<table>
<thead>
<tr>
<th>Potential Savings/Costs Changes</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Yard and over-the-road labor</td>
<td>Operations analysis</td>
</tr>
<tr>
<td>• Car utilization</td>
<td>Operations analysis</td>
</tr>
<tr>
<td>• Equipment and lading damage</td>
<td>Dynamic analysis</td>
</tr>
<tr>
<td>• Maintenance costs</td>
<td>Dynamic analysis</td>
</tr>
<tr>
<td>• Equipment wear</td>
<td>Dynamic analysis</td>
</tr>
</tbody>
</table>

- That fraction of labor savings paid to the union must be input to determine the net labor savings that can be realized.
- The number of years of union payout is also required to determine net labor savings.

- The depreciation method used by companies is required to determine the amount of tax shields that will be generated from investment in advanced equipment.

- That fraction of investment allowable for investment tax credit (ITC) will impact net benefits. The higher the ITC rate, the greater will be the net benefit to the system.

- The Federal Tax Rate is required input for calculation of after-tax net benefits.

Finally, inputs are required to set the structural parameters of the model, as shown in Table 27. Explanations of the function of each of these inputs follow.

- The number of cars in the system is required to determine the dollar amount available for hardware implementation on a per car basis.

- The number of years to system compatibility is needed to determine the point at which savings begin occurring for systems that require compatibility.

- The number of years cash flows are calculated influences amount available for advanced systems.

**An electrically connected train is an example of such a system.

††A freight system equipped with a given advanced technology is not a single asset (with a fixed lifetime that can be estimated), but rather a number of independent assets; namely, freight cars. Once a system that requires compatibility becomes compatible, it must be maintained; all new cars coming on the system must be equipped with the same advanced compatibility; has no fixed end point; and one must be chosen arbitrarily.

†These rates have a history of changing over time. At present, 10% is the allowable rate.
• The Asset Lifetime establishes the future points in time at which reinvestment must be made for systems that require compatibility.

• The fraction of cars replaced per year is that percentage of the car fleet that is taken out of service and replaced with new equipment. This fraction indicates the percentage of the fleet that will be equipped, from the beginning, with advanced hardware and this will not require retrofit.

• The fraction of retrofit cost required per new car production gives an estimate of the difference in cost in outfitting new cars with advanced hardware versus the cost of outfitting in-service cars.

• The Internal Rate of Return is the rate used to discount each year of cash flow.

Appendix B presents a description of the financial model computer program that will be used in future system analyses.

8. EXPECTED OUTPUT

When each of the components identified in Sec. 1 is evaluated by means of the methodology described in this report, the output is expected to be primarily an assessment of benefits and costs. Benefits will be presented as a stream of future cash flows that summarize the maximum acceptable investments per freight car. Costs will be presented in terms of anticipated investments required per freight car for existing, designed, or conceptualized equipment. As a first approximation, those systems for which benefits exceed costs (i.e., maximum acceptable investments are greater than anticipated investments) are worthy of further development. Since there is (sometimes considerable) uncertainty in the values of the parameters and variables used in the methodology, an uncertainty analysis will also be performed to determine possible ranges of benefits and costs, in addition to best estimates.

An institutional evaluation will be performed for those systems that would impact labor agreements or regulatory requirements. If labor agreements need to be changed, an estimate will be made of possible additional costs that may be incurred. If regulations are to be changed, they will be identified and possible changes suggested.
APPENDIX A

YARD SIMULATION MODEL

This appendix presents logic charts and the corresponding computer program listing for the yard simulation model. The purpose of this model is to keep track of time and cost elements for the work that is performed on a car as it passes through a yard. The major emphasis is on those tasks that have to do with the braking and coupling systems, but other tasks are included to give the model a more complete structure.

The model presented here should be viewed as a model for a hypothetical yard. It contains all the major tasks that are performed on cars as they pass through a yard; however, there are yards which may not fit the model because they perform the tasks in a different order.

There is one flow chart for each of the major yard operations: (1) inbound inspection and bleeding the cars, (2) classification (hump yard or flat yard), (3) pull down, and (4) connecting the air, charging the train, and the power brake test. Each chart allows several probability splits, depending, for example, on whether the train is yarded in one or two cuts, or whether the caboose is removed or classified as if it were just another car. In this respect the model is somewhat of a composite of many yards, because any one yard would most likely do these tasks either one way or the other.

The computer adds up the time for all tasks and multiplies by the number of cars classified per year. It then multiplies by labor rate of the crews performing the tasks or the rate for car time or locomotive time. The program is designed to calculate the difference between a baseline case and a change in one or more parameters. For example, the time to couple air hoses could be changed and the program would compute the corresponding change in time and cost for the following parameters:

- Road crew
- Yard crew
- Car inspectors
- Road locomotives
- Switch engines
- Car utilization.

The program is designed to run at BBN's Research Computer Center and uses a file system that is consistent with that center. The basic program is in the Fortran IV language.
UNIT CONSIDERED

1. MOVE SWITCH ENGINE TO CLASS TRACK
2. SIGNAL STOP
3. COUPLE ENGINE TO LEAD CAR
4. RELEASE HAND BRAKES

3.3
1. COUPLED
2. U.C. (STOPPED SHORT)
4. U.C. (REBOUND CLOSED–K)
5. U.C. (BYPASS–HI/LO)
6. U.C. (BYPASS–SIDE)
7. U.C. (BROKEN COUPLER)
8. U.C. (OTHER)

3.12
1. SET HAND BRAKES
2. PULL PIN
3. SIGNAL START AND UNCOUPLE CARS

3.16
1. MOVE CABOOSE TO END OF TRAIN
2. SIGNAL STOP
3. COUPLE CABOOSE TO CARS
4. CONNECT AIR LINES
5. OPEN ANGLE COCKS
6. CLOSE ANGLE COCKS BETWEEN CABOOSE AND LOCO
7. PULL PIN
8. SIGNAL START AND UNCOUPLE LOCO

3.11
1. MOVE BLOCK TO DEPARTURE TRACK

3.13
1. SIGNAL STOP
2. COUPLE TO WAITING BLOCK
3. PULL PIN
4. SIGNAL START AND UNCOUPLE CARS
FORMAT( ' NOT A COMMAND, TYPE HELP
    *** HELP FOR A LIST OF COMMANDS.' )
GO TO 70
C CHECK THAT USER IS FINISHED WITH
      ** PROGRAM
110   TYPE 120
120   FORMAT( ' ARE YOU FINISHED WITH THE PROGRAM? ', 3 )
    ACCEPT 91, ANS
    IF( ANS.NE. 'YES' ) GO TO 70
    CLOSE (UNIT=21)
    CLOSE (UNIT=22)
    STOP
C C ERROR PROCEDURES
200   TYPE 211
211   FORMAT( ' ERROR WHILE OPENING PAI ** L.HLP' )
    GO TO 15
210   TYPE 220
220   FORMAT( ' ERROR WHILE OPENING PAI ** L.DAT' )
    STOP
MAXLHP=8
DO 240 I=1,2??
240 MAP(I)=3
GO TO 15
C C C
C BLOCK DATA
COMMON /FAC/IFILB,MODAS(4), NEE

   ** 1,MATCH,LEVEL,IFILE,NPARAM,MODEL
   ** /DAT/PARAM(84)/RESULT(20)/ICHA
   ** /C(92)
2/LST/KEYWD(80),RESNAM(20)
3/HELP/MAF(23),MAXHELP
DATA ICANMP/1000/, IFILE/0/
DATA IFILB/0/, NPARAM/2
DATA MODAS/0/,DEFAULT
DATA MODEL/DEFAULT
C C
C CALL SUBROUTINE SPECIFIED BY USER
      **
SUBROUTINE LOOK(JANS)
COMMON /FAC/IFILB,MODAS(4), NEE

   ** 1,MATCH,LEVEL,IFILE,NPARAM,MODEL
   ** /DAT/PARAM(84)/RESULT(20)/ICHA
   ** /C(92)
5 MATCH=T
     IANS=JANS
     IF( IANS.EQ. 'HELP' ) CALL HELP
     IF( IANS.EQ. 'LIST' ) CALL HELP
     IF( IANS.EQ. 'SUN' ) CALL HELP
     IF( IANS.EQ. 'OUT' ) CALL OUTPUT
     IF( IANS.EQ. 'AP' ) CALL MAPDOS
     IF( IANS.EQ. 'BRIEF' ) BRIEF=1
     IF( IANS.EQ. 'CREATE' ) BRIEF=2
     IF( IANS.EQ. 'EXECUTE' ) CALL OFFL
     IF( IANS.EQ. 'ONLINE' ) CALL ONLINE
     IF( MATCH.EQ.1 ) TYPE 10
     FORMAT(2X) IANS=S
     RETURN
     END
C C
C READ FROM RAIL, HLP AND OUTPUT
SUBROUTINE HELP
INTEGER IRHT(3),LWITH(4),HLPPOR(16),IOUT(72),BLANK(15),TEXT(15)
COMMON /FAC/IFILB,MODAS(4), NEE

   ** 1,MATCH,LEVEL,IFILE,NPARAM,MODEL
   ** /DAT/PARAM(84)/RESULT(20)/ICHA
   ** /C(92)
C C C
C IOUT: AREA TO STORE A LINE OF
      ** CHARACTERS
C BLANK: DUMMY ARGUMENT
C TEXT: AREA TO STORE A LINE IN
      ** A5 FORM
C MAP CONTAINS THE STARTING POINT
      ** IN A CHAIN OF RECORDS
      ** THAT

   CONTAINS THE MESSAGE TO
   ** BE OUTPUT.
   I=MAP(LEVEL)
   GO TO 10
   C ENTRY POINT FOR THE REST OF THE
      ** PROGRAM TO ACCESS
      ** MESSAGES.
   C SUBROUTINE HELP
   C FIND STARTING POINT AS BEFORE
   I=AP(12)
   C RECORD NUMBERS LESS THAN 8 ARE NOT
      ** PRESENT
   IF(I.LE.8) GO TO 50
   C RECORDS GREATER THAN MAXHELP ARE
      ** NOT PRESENT
   IF(I.GT.MAXHELP) GO TO 50
   C READ A LINE
   READ(22,L19,ERR=32) J,IOUT,K
   19 FORMAT(13,72A1,11)
   20 FORMAT(13,14A5,82,11)
   DO 23 L=72,2,-1
   23 IF(IOUT(L).NE. ' ') GO TO 310
       WRITE(19,307)
   30 FORMAT(1X)
   GO TO 27
   IF(IOUT(L).EQ. ' ') GO TO 310
   IF(IOUT(L).EQ. ' ') I=1
   WRITE(19,322) (IOUT(LL),LL=1,L)
   320 FORMAT(1X,72A1)
   GO TO 27
 50
338 L=L-1
IF([OUT(L),EQ,''): I=L-1
ENCOD((50,300,HLF)FOR) IFRET,[IOUT
**R([L]),LL=1),L4IT **H
340 FORMAT(80A1)
WRITE(19,HLF)FOR)
GO TO 27
C DOLLAR SIGN SUPPRESSES CARRIAGE **RETURN SO USER MAY **RESPOND
C K EQUALS 1 ONLY AT END OF CHAIN **OF LINKS IN MESSAGE **E
27 IF(K.EQ.1) GO TO 25
C J IS RECORD NUMBER FOR NEXT LINE **I IS R.N. OF CUR **RENT LINE
I=J
GO TO 10
C SUCCESSFUL COMPLETION, RETURN TO **CALLING PROGRAM
25 MATCH=1
LEVEL=3
RETURN
C ERROR IN SUBR., DISPLAY DIAGNOST **TC INFORMATION
30 TYPE 40,LEVEL,I
FORMAT(' PROGRAM ERROR. LEVEL=', **13,' I=',I3)
GO TO 25
C NO MESSAGE IS AVAILABLE, OUTPUT **GENERAL MESSAGE
50 TYPE 60
60 FORMAT(' TYPE STOP TO RETURN TO **MAIN LEVEL.1')
GO TO 25
C CHANGE RESPONSE TO HELP ENTRY LHELP
C PROMPT FOR LEVEL NUMBER FOR MESS **AGE TO BE CHANGED
215 TYPE 225
225 FORMAT(' LEVEL=',I3)
READ(5,230,BFR=25) LEVEL
230 FORMAT(I3)
C CHANGE MESSAGE FOR CURRENT LEVEL ENTRY LHELP
C NEW: 0 IF LINE WILL REPLACE A **N ALREADY EXISTING **RECORD IN
C RAILLLE
C 1 IF NEW RECORD IS CREATE **ED
NEW=3
C FIND STARTING POINT IN CHAIN FOR **EXISTING MESSAGE **(SUER, HELP)
K=MAP(LEVEL)
K WILL BE LESS THAN 9 ONLY IF NO **MESSAGE EXISTS
C ICHMAP: 1 IF MAP HAS CHANGED, 0 **IF NO CHANGE MADE **YET
ICHMAP=0
IF(K.GT.8) GO TO 65
C NO MESSAGE EXISTS, CREATE A NEW **RECORD
MAP(LEVEL)=MAXHLP+1
NEW=1
C PROMPT USER FOR MESSAGE MAP HAS CHANGED SO REMEMBER TO **GET IT WHEN PIN **ISHED
ICHMAP=1
65 TYPE 70
70 FORMAT(' ENTER A LINE.1)
ACCEPT 30,TEXT
80 TYPE 100
90 FORMAT(' DO YOU WANT TO ENTER AN **OTHER LINE (A CONT **I MATION)?Z'),$)
C M: 'NO' IF THIS IS TO BE LA **ST LINE IN MESSAGE
ANYTHING ELSE MEANS YES
91 FORMAT(A5)
100 TYPE 100
LAST=0
IF(M.EQ.'NO') LAST=1
C IF THIS RECORD IS NEW INCREMENT **MAXHLP
IF(N.EQ.1) GO TO 100
C READ LOCATION OF NEXT RECORD IN **EXISTING CHAIN
READ(22#R,20,ERR=200) NEXT,CHAIN **J
C IF THIS IS LAST LINE IN EXISTING **CHAIN, NEXT LINE **WILL BE NEW
IF(NEXT.EQ.0) GO TO 190
C IF NEW LINE IS BEING CREATED AND **WILL BE LAST, END **THE CHAIN
120 IF(N.EQ.1.AND.LAST.EQ.1) NEXT= **2
C WRITE LINE TO FAIL.HLP
WRITE(22#K,29,FR=30) NEXT,TEXT, **LAST
130 IF FINISHED WRAP-UP
WRITE(22#K,29,FR=30) NEXT,TEXT, **LAST
C CHANGE NEXT TO CURRENT AND REPEA **T
% =N EXT
GO TO 65
C WRITE NEW VERSION OF MAP IF IT II **AS CHANGED
150 MATCH=1
C SKIP IF NO CHANGE
IF(ICHMAP,EQ.0) GO TO 179
WRITE(22#1,290) MAXHLP,(MAP(I),I **=1,23)
WRITE(22#2,290) (MAE(I),I=24,47)
WRITE(22#3,290) (MAP(I),I=48,71)
WRITE(22#4,290) (MAP(I),I=72,95)
WRITE(22#5,290) (MAP(I),I=96,119)
**
WRITE(22#6,290) (MAE(I),I=123,14 ***)
**)
WRITE(22#7,290) (MAP(I),I=144,16 ***)
**)
WRITE(22#8,290) (MAP(I),I=169,19 ***)
290 FORMAT(24T3,4X)
C INCREMENT MAXHLP BECAUSE RECORD **IS BEING CREATED
C MAXHLP=MAXHLP+1
179 RETURN
C C SET CURRENT RECORD NUMBER TO NEW **LY CREATED RECORD
180
K=MAXHELP
NEXT WILL BE CREATED AT THE NEXT
** ROUND
NEXT=MAXHELP+1
NEW LINE HAS BEEN CREATED
NEW=1
GO TO 120

NEW MESSAGE ENDS ON SAME LINE AS
** OLD MESSAGE SO NO
** CHANGE MADE

190 IF(LAST.EQ.1) GO TO 130
NEW MESSAGE IS LONGER THAN OLD M
** MESSAGE
NEXT=MAXHELP+1
NEW=1
GO TO 110
PRINT DIAGNOSTIC

210 FORMAT(9 PROGRAM FPROC, READ22 A
** K=1,I)
GO TO 25

ENTRY LOAD

SUBROUTINE LOAD
COMMON /FAC,IFBRI,MODBAS(4),NRE
**WS
1,MATCH,LEVEL,NFILE,NPARM,MODEL
**{4),DIRF(4,29)
1/DAT/PARM(40),RESULT(23),ICHAN
**2(80)
2/KEY/KEYD(12),NRE NAM(29)
INTEGER ANS(4)
GO TO 100

REST OF PROGRAM CAN TEMPORARILY
** STORE AND RETRIEVE
** DATA
ENTRY ALGAD(12)

1=12
C SKIP A RECORD BECAUSE FIRST ENTR
**Y IN RAIL.OAT IS N
** FILE
5 I=1+1
READ PARAMETERS INTO CURRENT FIL
** NAME, CURRENT PAR
** AMETERS
READ(21#I,1,IFN=50) IMODEL,PARA
**.N,NEFM
10 FORMAT(4AS,8:14,8,13)
DO 24 J=1,13
C RESET ICHANG BECAUSE OLD CHANGES
** ARE NO LONGER VAL
** ID
20 ICHANG(J)=0
MATCH=1
RETURN
50 CALL ERRNSW(I,J)
TYPE 60,1,J
60 FORMAT(9 PROGRAM FPROC IN LOAD.
** FIRST='13,J', S
**SECOND='13,13)
GO TO 43
C PROMPT USER FOR FILENAME

110 FORMAT(* LOAD VALUES STORED IN F
** FILE:13,5)

115 LEVEL=102
ACCEPT 123,ANS
FORMAT(485)
C FIND FILENAME IN DIRECTORY
CALL LOCATE(ANS,1)
C SEE SUBR. LOCATE FOR DESCRIPTION
** CP MATCH IN THIS
** CASE
GO TO (5,40,183,1192)
C FILE NOT FOUND IN DIRECTORY, THR
** MAIN

130 FORMAT(' FILE NOT FOUND,')
GO TO 100
C LOAD BASE CASE AS SPECIFIED BY M
** ODDS
ENTRY LOAD

CALL ALGC(MODBAS,1)
C IF NOT FOUND TYPE WARNING
1F(MATCH.NE.1) GO TO 170
C SKIP A RECORD BECAUSE OF RAIL. DA
** T

150 I=1+1
C DON'T CHANGE IMODEL
READ(21#I,1,J,IFN=50) MODBAS,PARA
**.N,NEFM
GO TO 40
C LOAD BASE CASE AS SPECIFIED BY 1
** .SEM
ENTRY LOAD

PROMPT FOR FILENAME

160 TYPE 110
LEVEL=107
ACCEPT 123,ANS
IF(ANS(1).EQ."STOP") GO TO 43
C FIND RESPONSE IN DIRECTORY
CALL LOCATE(ANS,1)
GO TO (152,40,160,170)
MATCH

170 TYPE 190
GO TO 165

190 FORMAT(9 THE FILE SPECIFIED IS
** NOT BASE CASE IS NOT F
** OUND ',/10,
1,' PLEASE REENTER OR TYPE STOP;
**.5)
C LOAD AS SPECIFIED BY IMODEL
ENTRY LOAD

C FIND NAME OF CURRENT MODEL IN DI
** RCTORY
CALL ALGC(1MODE1,1)
C IF NOT FOUND GIVE WARNING
1F(MATCH.NE.1) GO TO 200
C LOAD VALUES IN FILE
GO TO 5

210 FORMAT(' FILE SPECIFIED FOR CURRE
** NT MODEL NOT FOUN
** D ',10
1,' PLEASE REENTER OR TYPE STOP;
**.5)
GO TO 115
C LOAD STORED VALUES OF ICHANG
ENTRY LDCHNG(I3)
I=13+1
C
SEE SUBR. DIFF FOR REASON FOR ST
** ERM ICHANG
READ(21,1,229,ERR=5) ANS,ICHANG
220
FORMAT(4A5,8J11,1843X)
GO TO 40
END

C
C
C
C
CHANGE VALUE OF A PARAMETER
C
THIS SUBROUTINE SEARCHES THE LIST
**F KEYWD(00) FOR TH
**E KEYWORD
C
THAT THE USER ENTERS. IF IT IS F
**ONE CALL A HELP TO
** TYPE THE
C
QUESTION CORRESPONDING TO THE KE
**YWD. THE USER TH
**EN ENTERS
C
THE NEW VALUE AND RETURNS TO THE
** CALLING SUBROUTINE.
**E. IF THE
C
USER'S RESPONSE IS NOT A NUMBER,
** REPEAT THE RESPONSE
** AND STOP
C
CHECK IT AGAINST KEYWD WHICH WI
** LI RESULT IN A JOB
** NAME
C
MESSAGE. ENTRY CHANGE IS TO ALLO
** THE ABBREVIATED
** FORM,
C
C <KEYWORD> INSTEAD OF CHANGE <R
**THEN> <KEYWORD>
** THIS IS
C
DONE BY THE READ IN SUBR. LOOK
SUBROUTINE CHANGE
COMMON /FAC/IBRIF,MODBAS(4),NRE
**
1, MATCH, LEVEL, NFILE, NPARM, IMODEL
**F (4), IDIR(4,23)
1/DAT/PARAM(53), RESULT(20), ICHAN
**G (2)
2/LST/KEYWD(80), RESNM(20)
INTEGER TEXT(13)
GO TO 10
ENTRY CHANGE(INCRED)
IANS=IWORD
GO TO 35
TYPE 20
10
20
FORMAT(' KEYWORD OF PARAMETER:',
** *
LEVEL=103
ACCEPT IF,IANS
10
FORMAT(45)
IF(IANS.EQ.'STOP') GO TO 125
CALL IHEIF(IANS)
IF(MATCH,EQ,1) GO TO 10
35
IF(IANS.EQ.1 ) GO TO 125
DO 50 I=1,83
IF(IANS.NE.KEYWD(1)) GO TO 50
C
C SUCCESSFUL SEARCH
GO TO 100
50
CONTINUE
C
C KEYWD NOT FOUND
TYPE 56
60
FORMAT(' THE KEYWORD YOU ENTERED
** IS NOT ON THE LIST
**. TYPE ')
1,'LIST FOR A LIST',/,' OF KEYWD
**DS. TYPE STOP IF
**Y IF DO NOT '
2,' WANT TO CHANGE A PARAMETER.'
GO TO 10
C
C
C
C
TYPE QUESTION, READ ANSWER
CALL AHEIF(I)
110
READ(5,124,FRM=1.10) X
120
FORMAT(E14.0)
PARAM(I)=X
ICANG(1)=1
125
MATCH=I
RETURN
C
C
READ ERROR
LEVEL=I
ACCEPT IF,IANS
IF(IANS.EQ.'STOP') GO TO 125
CALL IHEIF(IANS)
IF(MATCH,EQ,1) GO TO 100
GO TO 35
END
C
C
C
C
OUTPUT RESULTS
SUBROUTINE OUTPUT
COMMON /FAC/IBRIF,MODBAS(4),NRE
**
1,MATCH,LEVEL,NFILE,NPARM,IMODEL
**F (4),IDIR(4,23)
1/DAT/PARAM(53),RESULT(20),ICHAN
**G (2)
2/LST/KEYWD(30),RESNM(20)
TYPE 10,IMODEL
16
FORMAT(' MODEL USED: ',4A5,/'
1,' THE FOLLOWING PARAMETERS HAVE
** BEEN CHANGED: B)
DO 3I I=1,NPARM
IF(ICHANG(I).EQ.2) GO TO 30
TYPE 25,KEYWD(I),PARAM(I)
FORMAT(2X,A5,3X,F14.2,2X,5)
J=I
IF(IBRIEF,EQ,1) GO TO 25
CALL AHEIF(J)
25
TYPE 35
FORMAT(2X)
CONTINUE
TYPE 40,FCDBAS
FORMAT(/'/', 'BASE CASE: ',4A5
1,' USING THESE PARAMETERS THE
** FOLLOWING RESULTS
** ARE:
1,'OBTAINED, '
DO 50 I=1,NPARS
TYPE 24,FCDBAS(I),RESULT(I)
J=I+80
IF(IBRIEF,EQ,3) GO TO 45
TYPE 35
GO TO 50
CALL AHEIF(J)
CONTINUE
TYPE 40
50
CONTINUE
50
CONTINUE
TYPE 70
53
LIST CURRENT VALUE OF ALL PARAMETERS

SUBROUTINE LIST
COMMON /PARA/LEVEL,NFILE,NPARM,IMODEL
**5
1,MATCH,LEVEL,NFILE,NPARM,IMODEL
**5,1,DIR(4,23)
1/DAT/PARM(80),RESULT(20),ICHAN
**G(80)
2/LIST/KEYWD(80),RESNAM(20)
TYPE 4,IMODEL,MODEAS
FORMAT(///,1'CURRENT MODEL:','4A
**5/)
1,'BASE CASE:','4A5')
TYPE 5
FORMAT(,'KEYWORD VALUE',/)
TP(NPARM,GE.1)GO TO 30
TYPE 10
FORMAT('PROGRAM ERROR,NPARMLE
**55 THAN 1')
20
MATCH=1
RETURN
30
DO 50 I=1,NPARM
TYPE 35,KEYWD(I),PARAM(T)
FORMAT(1X,A5,1X,P9.4,2X,5)
J=I
IF(SAME,EQ.1)GO TO 36
CALL AHELP(J)
50
CONTINUE
FORMAT(1X)
CONTINUE
GO TO 20
END

SUBROUTINE LOCATE(ANS,I)
COMMON /PARA/LEVEL,NFILE,NPARM,IMODEL
**5
1,MATCH,LEVEL,NFILE,NPARM,IMODEL
**5,1,DIR(4,23)
1/DAT/PARM(80),RESULT(20),ICHAN
**G(80)
2/LIST/KEYWD(80),RESNAM(20)
INTEGER ANS(1)
IF(ANS(1).EQ.'STOP')GO TO 60
CALL IOC(K(ANS(1))
IF(MATCH,EQ.1)GO TO 70
EMPTY ALOC(ANS,I)
DO 30 J=1,NFILE
DO 70 I=1,4
IF(ANS(J).NE.IDIR(J,I))GO TO 30
GO TO 50
CONTINUE
GO TO 80
30
CONTINUE
STOP
MATCH=2
RETURN
C
C
REP FILE PROMPT
MATCH=3
RETURN
C
C
NOT FOUND
MATCH=4
RETURN
END

STORE CURRENT PARAMETERS IN FILE
SUBROUTINE STORE
COMMON /PARA/LEVEL,NFILE,NPARM,IMODEL
**5
1,MATCH,LEVEL,NFILE,NPARM,IMODEL
**5,1,DIR(4,23)
1/DAT/PARM(80),RESULT(20),ICHAN
**G(80)
2/LIST/KEYWD(80),RESNAM(20)
INTEGER ANS(1)
GO TO 100
ENTRY ASTORE(I2)
I=I+1
I=I+1
WRITE(21,I,ERR=50)IMODEL,PAR
FORMAT(4A5,3E14.5,13)
MATCH=1
RETURN
50
CONTINUE
FORMAT('PROGRAM ERROR IN STORE.
**55
GO TO 40
40
TYPE 118
100
FORMAT('STORE IN FILE CALLED:','
**55
LEVEL=104
ACCEPT 128,ANS
FORMAT(4A5)
CALL LOCATE(ANS,I)
GO TO (10,40,130,132) MATCH

PRINT DIRECTORY
SUBROUTINE DIR
COMMON /PARA/LEVEL,NFILE,NPARM,IMODEL
**5
1,MATCH,LEVEL,NFILE,NPARM,IMODEL
**5,1,DIR(4,23)
1/DAT/PARM(80),RESULT(20),ICHAN
**G(80)
2/LIST/KEYWD(80),RESNAM(20)
IF(NFILE.LE.(NFILE)GO TO 30
DO 10 I=1,NFILE
TYPE 20,I,DIR(J,I),J=1,4
20
FORMAT(1X,I2,5X,4A5)
30
MATCH=1
RETURN
40
CONTINUE
FORMAT(1X)
CONTINUE
GO TO 20
END

PRINT DIRECTORY IS EMPTY
**5
NFILE=3
GO TO 30
END

FIND LOCATION OF FILE IN DIRECTORY
**5
C FILE=NAME FILE+1
I=FILE
DO 147 J=1,4
IDIR(J,1)=ANS(J)
140 MODEL(J)=ANS(J)
WRITE(21 #1, 995) NAME
995 FORMAT(I3,114?X)
GO TO 10
C C
STORE CURRENT VALUES OF ICHANG
ENTRY STRCHG(I3)
150 I=3+1
160 WRITE(21 #1,187,ERW=50) IMODEL,IC
**IANG
180 FORMAT(4A5,8P11,1P43X)
GO TO 40
END
C
C
READ THE DIRECTORY FROM UNIT 21
SUBROUTINE REDIR
COMMON /FAC/IBRIEF,MODBAS(4),NRE
**S
1,MATCH,LEVEL,NAME,NPARAM,IMODEL
**4,(IDIR(4,23)
5 FORMAT(4A5,11230)
READ(21 #1,183X) NAME
IF(NAME.LT.9) GO TO 32
120 READ(21 #1,22,ERR=132) (ITIE(J,J)=1,1,4)
GO TO 10
200 NAME="'
30 TYPE 113
110 FORMAT(' PROGRM ERROR IN REDIR.
**')
GO TO 200
END
C C
C
REMOVE A FILE FROM THE DIRECTORY
SUBROUTINE DFETE
COMMON /FAC/DFETE,MODBAS(4),NRE
**S
1,MATCH,LEVEL,NAME,NPARAM,IMODEL
**4,(IDIR(4,23)
INTEGER ANS(4)
DIMENSION XPARM(4C)
GO TO 13
ENTRY ADFE(12)
I=12
GO TO 50
13 TYPE 20
20 FORMAT(' DELET FILE NAMED:1,5)
LEVEL=10
ACCEPT 3C,ANS
FORMAT(4A5)
CALL LOCATE(ANS,T)
GO TO (50,47,10,90) MATCH
40 MATCH=1
RETURN
C
C
IF(1,LT,NAME) GO TO 50
NAME=NAME+1
WRITE(21 #1,995) NAME
GO TO 40
C
C
WRITE(21 #1,995) NAME
995 FORMAT(I3,114?X)
DO 80 J=1,NFILE+1
K=J+1
READ(21 #1,70,ERR=110) ANS,XPARAM
**XPARM
70 FORMAT(4A5,8E14.13)
WRITE(21 #1,71) ANS,XPARAM,XPARM
CONTINUE
CALL REDIR
GO TO 40
90 TYPE 10 I
101 FORMAT(' FILE NOT FOUND.
')
GO TO 10
110 CALL ERRSNS(1,J)
TYPE 129,8,1,J
120 FORMAT(' PROGRAM ERROR IN DELETE
**. K='1,J,' 'I='1,13,
** J='1,13)
GO TO 40
END
C
C
DO SIMULATION
SUBROUTINE PREGK
IMPLICIT REAL(A-Z)
INTEGER I,NRE,MATCH,LEVEL,NAME,R
**ESNAM
1,NPARAM,ICHANG
READ T(9)
COMMON /FAC/PRIE,MODBAS(4),NRE
**S
1,MATCH,LEVEL,NAME,NPARAM,IMODEL
**4,(IDIR(4,23)
2 ASTRNAM(40),RESNAM(20)
3 DAT/P1AI,P1BY,PRCY,HER,HBC,PCT
**PT,SHB,FRB,WIC,C
**AC
1,0AC,OK,CH,SH,SSP,CUR,RAB,CBOC,
**CC,CBP,CCB,CCT,CCT,CCT,CCT,
**C,MP,SA,P2AY
2 ,P2AY,P2CY,HBC,CTPT,AJL,HIC,P
**3N(9),P3BY,P3CY,P3
**DPD,P3DY,P3DY
3,CTPT,4AY,P4BY,P4CY,ECSZ,YCST
**LI,PT,PLT,PLT,RELC
**C,RE,RC
4,NULI(22)
8,JRC,BCY,UCI,URL,USE,UC,CURC,CY
**TC,UC,K,CUS,C
**UC,NULI(8)
8,ICHANG(8P)
C
C
EQUATIONS
CHECK FOR DIVID BY ZERO
IF(VHC,EC,3,8) GO TO 200
IF(CPL,EC,3,8) GO TO 210
IF(CTPTD,EC,3,8) GO TO 220
YARD TRAIN
11 = WIC+CPT/2+CAC+RAB+OK+5I
12 = WIC+CPT/2+CAC+RAB+OK+5I
55
T13 = MT + SA + HBC* (SHE + 2 * WC) + CAC + OK
** + SU
T14 = MT + SSE + CUP + CH + OAC + CPCO
T15 = WIC * CPT / 2 + HBC * (SHB + 2 * WIC) + CA
** CCRAB + OK + SU
T16 = T13
T17 = MT + SSE + CUP + CH + OAC + HBC * (RHB + 2
** WIC)
T18 = MT + SA + HBC * (SHB + 2 * WIC) + CAC + OK
** + SU
T19 = MT + SSE + CUP + EC + OK + SU
T21 = BL + CPT
TY = P1A1 * T11 + (1 - P1A1) * ((P1BY * T12
** + T14) + (1 - P1BY) * (T1
** + T17))
T1 = T110
T10 = TY + T1
CLASSIFICATION - WHAT YOU ARe
T21 = MT + SSE + CUP
T22 = HBC * (SHB + 2 * WIC)
CPC = CPT / CPTDT
T23 = HBC * (RHB + WC) + WIC * CPC + HBC * (S
** WIC) + OK + SU
T24 = MT
T25 = ACL / (VHC + BB)
T26 = 10
T27 = 13
PFC UT = T21 + P2AY + T22 + (1 - P2AY) * T23 +
** T24
TCS = P2BY * T26 + (1 - P2BY) * T25
T2 = CUTPT + IP CUT + CPT + TCS
PULL DOWN AND CHARGE BRAKE FOR
T31 = MT
T32 = SSE + CUP + HBC + RHB
T(1) = 0
T(2) = 5
T(3) = 5
T(4) = 5
T(5) = 15
T(6) = 15
T(7) = 60
T(8) = 5
T(9) = 0
T13 = 0
D0 4 I = 1, 9
T33 = T33 + F3A1 (I) * T(I)
T33CT = (T33 + WIC) * CPT / CPTDT
T34 = MT
T35 = H3T * (SHB + WC) + OK + SU
T36 = SSE + CUP + OK + SU
T37 = SSE + CUP + CH + 2 * OAC + WIC + CAC +
** OK + SU
T38 = CPT * (WIC + CH) + CAC
T39 = MT + SSE + CUP + CH + OAC + CPTC
T310 = 2
T311 = MT + CH + OAC + C610 + CAC + MT
T312 = MT + SSE + CUP + CH + OAC + C670
T313 = HBT * (2 * WC + R HB)
TPO = T311 + T32 + T33 + T34 + P1BY * T35 + (1 -
** 3BY) * T36 + P3BY * T37
** T38
TRC1 = P3DB + T19 + (1 - P3D B) * T312 + T3
** 11
TYA = P1DY * T11
TYE = P4DY * T11
T3 = TPD * TRCL + TYA + TYE

POWER BRAKE TEST
T41 = 13
T42 = 30
T43 = 5
T44 = 3
T45 = 2
T46 = 2
T47 = 3
T4 = T41 + (1 - P4 BY) * T42 + T43 + (1 - P4
** CY) * T47

COST EQUATIONS
JRC = 5A6 , 346 * (T1 + TRCL + T4) * RCSZ / CP
** T
JYC = 5A6 , 346 * (C1 * T1 * CPT * P2CY * T27 +
** P3D * T47) / CP
JBL = 1212692 * RLP T * (T1 + TRCL + T4) / CP
** T
JSE = 1212692 * (T2 + TPD + TYE) / CP
UC = 1212692 * (T1 + P6) * ((CUTPT + 1) * T P
** )

CUR = RLA1 + HBC
CUR = RAE + WC
CUR = RAE + UC
CUR = RPLE + UVL
LUS = RSL + US
LUS = UC

MATCH = 1
RETURN
ENTRY SET NAME
ST VALUES FOR MODEL SPECIFIC VA
** RIAELES

NPARM = 58
NRE = 12
NAM (1) = P1A1
NAM (2) = P1BY
NAM (3) = P1CY
NAM (4) = HBT
NAM (5) = VHC
NAM (6) = CPT
NAM (7) = LPT
NAM (8) = SHB
NAM (9) = FE
NAM (10) = CAC
NAM (11) = CAC
NAM (12) = CAC
NAM (13) = OK
NAM (14) = CH
NAM (15) = SH
NAM (16) = SSE
NAM (17) = CUP
NAM (18) = RAP
NAM (19) = CBTO
NAM (20) = CBCO
NAM (21) = CBC72
NAM (22) = CBC76
NAM (23) = BC
NAM (24) = MT
NAM (25) = SA
NAM (26) = E2AY
NAM (27) = E2BY
NAM (28) = E2CY
NAM (29) = HBCC
NAM (30) = CUTPT
NAM (31) = ACL

56
DO 23 I=1,22:
IF(MAP(I,J,E,8))GO TO 22
10
TYPE 19,I
FORMAT(/',LEVEL=','l3)
J=I
CALL AHELP(J)
20
CONTINUE
MATCH=1
RETURN
END
C
C
C
CALL PROGRAM, DO DIFFERENCING
SUBROUTINE DIFF
DIMENSION XRES(22)
COMMON /FAC/I,BRIEF,MODELS(4),NRF
**S
I,MATCH,LEVEL,NFILE,NPARAM,MODEL
**S(4),IDIR(4,2)
1/DAT/PARAM(5),RESULT(23),ICHAN
**S(58)
C
C
STORE CURRENT VALUES
NFILE=NFILE+2
J=NFILE-1
CALL ASTORE(J)
CALL STRCHG(J+1)
C
C
COMPUTE BASE CASE
CALL LOAD
5
CALL PREGM
DO 10 I=1,NRES
XRES(I)=RESULT(I)
10
C
C
COMPUTE CURRENT MODEL
CALL MAAC(J)
15
CALL PREGM
CALL LDCHG(J+1)
CALL ADEI(J+1)
CALL ADEL(J)
C
C
COMPUTE DIFFERENCES
DO 23 I=1,NRES
RESULT(I)=RESULT(I)-XRES(I)
CALL COUTPUT
MATCH=1
RETURN
END

C
C
C
DIRECT OUTPUT FOR UNIT 19 TO DIS
**K FILE
SUBROUTINE OFFLI
CLOSE(UNIT=19)
OPEN(UNIT=19,DEVICE='DSK',FILE='**OFFLINE.TXT',ACCES
**S='SRQOUT')
RETURN
C
C
RESTORE OUTPUT TO TERMINAL
ENTRY ONLINE
CLOSE(UNIT=19)
OPEN(UNIT=19,DEVICE='TTY',ACCES
**S='SEQINOUT')
RETURN
END

C
C
C
LIST CONTENTS OF HELP FILE
SUBROUTINE MAPD
COMMON /FAC/I,BRIEF,MODELS(4),NRF
**S
I,MATCH,LEVEL,NFILE,NPARAM,MODEL
**S(4),IDIR(4,2)
1/HLP/MAP(24),MAXHLP

The financial model program is divided into three phases. On entering the program, the user inputs parameter values, instructs the computer to solve the model, and then specifies the form of output. For each phase, the user types one of the following commands:

I. Input
   - Change
   - Model

II. Computations
   - Solve
   - Variable

III. Output
   - Graph
   - List
   - Print
   - Create
   - Delete

For each command, the computer enters the corresponding subroutine. Subroutine Change allows the user to specify a new value for any parameter. Model, which the user enters at the start of the program, asks for values for all the parameters. Subroutine Solve evaluates the financial equations and stores the results. Variable allows different cash flow patterns to be studied.

The output of the financial model is in three parts. First, subroutine List types out the parameter values. Second, subroutine Print types out the results obtained from the financial model. Third, subroutine Graph plots the results of the model. Create and Delete are used to enter and remove extra lines in the output.

The financial model is comprised of a set of equations in subroutine Solve. For each year the start-up costs (if any), annual costs, investment tax credit, and depreciation tax credit are computed. Also computed are labor savings after completion. Because all the costs are proportional to the cost of retrofitting a single car, the dollars available per car is obtained by dividing the total savings by the total cost.

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FIG. B.1 (Cont.). FINANCIAL MODEL FLOWCHART.
Compute Labor Savings
If YEAR is greater than start-up period and LESS than stop-payment-year
SAVINGS(YEAR) = Laborsavings *(1-Tax Rate) x (1-Payment to Union) x Inflation

Compute Other Savings
If System is Complete
OTHER(YEAR) = Savings x (1-Tax Rate) x Inflation

Compute Sum of Per $ Cash Flows
A(YEAR) = START(YEAR) + ANNUAL(YEAR) + TAXCR(YEAR) + DEPRT(YEAR)

Compute Sum of Fixed Flows
B(YEAR) = SAVING(YEAR) x OTHER(YEAR)

YEAR = YEAR + 1

No
Yes

B

FIG. B.1 (Cont.). FINANCIAL MODEL FLOWCHART.
**FIG. B.1 (Cont.). FINANCIAL MODEL FLOWCHART.**
MODEL

THIS IS A MODEL TO ESTIMATE THE AMOUNT THAT CAN BE SPENT PER FREIGHT CAR FOR ADVANCED BRAKING AND COUPLING.

FOR HOW MANY YEARS SHOULD THE CASH FLOWS BE CALCULATED? 21
HOW MANY YEARS DOES THE SYSTEM TAKE TO BECOME COMPATIBLE? 5
HOW MANY CARS ARE IN THE SYSTEM? 1700000
WHAT FRACTION OF THE CARS HAVE TO BE REPLACED EACH YEAR? 0.037
WHAT FRACTION OF RETROFIT COST IS REQUIRED FOR NEW PRODUCTION (PER CAR)?: 5
FRACTION= 50.0%
IS THIS CORRECT? YES
WHAT IS THE LABOR SAVINGS PER YEAR THAT IS SUBJECT TO UNION PAYOUT? 220000000
FOR HOW MANY YEARS WILL SAVINGS BE PAID TO THE UNION? 10
WHAT FRACTION OF LABOR SAVINGS ARE PAID TO THE UNION? 0.25
WHAT IS THE ANNUAL SAVINGS NOT SUBJECT TO UNION PAYOUT? 0
WHAT IS THE TAX RATE FOR THE RAILROAD INDUSTRY? 0.46
WHAT FRACTION OF INVESTMENTS ARE DEDUCTIBLE FOR INVESTMENT TAX CREDIT? 0.10
WHAT IS THE INFLATION RATE FOR:
MATERIALS (IN PERCENT)? 0.7
LABOR (IN PERCENT)? 0.87
WHAT IS THE LIFETIME OF THE ASSET? 16
WHAT METHOD OF DEPRECIATION DO YOU WANT TO USE?
STRAIGHT
DOUBLE
SUM
-STRaight LINE
-DOUBLE DECLINING BALANCE
-SUM OF YEARS DIGITS

FIG. B.2. QUESTIONS ASKED BY FINANCIAL MODEL.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>KEYWORD</th>
<th>CURRENT VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER OF YEARS IN ANALYSIS</td>
<td>LIMIT</td>
<td>21</td>
</tr>
<tr>
<td>YEARS BEFORE SYSTEM IS COMPATIBLE</td>
<td>COMPATIBLE</td>
<td>5</td>
</tr>
<tr>
<td>NUMBER OF CARS</td>
<td>NUMBER</td>
<td>170000000.000</td>
</tr>
<tr>
<td>ATTRITION RATE</td>
<td>ATTRITION</td>
<td>0.037</td>
</tr>
<tr>
<td>NEW COST OF EQUIPMENT</td>
<td>FRACTION</td>
<td>0.500</td>
</tr>
<tr>
<td>INVESTMENT TAX CREDIT</td>
<td>INVESTMENT</td>
<td>0.100</td>
</tr>
<tr>
<td>TAX RATE</td>
<td>TAX</td>
<td>0.460</td>
</tr>
<tr>
<td>LOSS TO UNION</td>
<td>UNION</td>
<td>0.250</td>
</tr>
<tr>
<td>LABOR SAVINGS</td>
<td>SAVINGS</td>
<td>220000000.000</td>
</tr>
<tr>
<td>YEARS SAVINGS ARE LOST TO UNION</td>
<td>LOSE</td>
<td>10</td>
</tr>
<tr>
<td>OTHER SAVINGS</td>
<td>OTHER</td>
<td>0.000</td>
</tr>
<tr>
<td>INFLATION: MATERIALS</td>
<td>INFLATION</td>
<td>1.100</td>
</tr>
<tr>
<td>LABOR</td>
<td></td>
<td>1.087</td>
</tr>
<tr>
<td>OTHER</td>
<td></td>
<td>1.100</td>
</tr>
<tr>
<td>MINIMUM DISCOUNT RATE</td>
<td>RATES</td>
<td>5</td>
</tr>
<tr>
<td>MAXIMUM DISCOUNT RATE</td>
<td>RATES</td>
<td>25</td>
</tr>
<tr>
<td>DEPRECIATION</td>
<td>DEPRECIATION</td>
<td>16</td>
</tr>
<tr>
<td>LIFETIME OF ASSETS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUM OF YEARS DIGITS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIG. B.3. EXAMPLE MODEL INPUTS.
FIG. B.4. EXAMPLE OF GRAPHIC MODEL OUTPUT.
MODIFY PARAMETERS
SUBROUTINE CHANGE(S,MATCH)
COMMON LINES, DATA(26,2,10), POINT
**10, LABEL(10,2), W
**IDTH(2)
1, YLABEL(41!), XLABEL(2), LIMIT, ICO
**MP, X, NCAR, ATTRAT
**ATINF
2, LABINF, LABORS, LOW, HIGH, PAYSTP,
**FRAc, FRIcT, TAXRAT,
**UPAYRT
3, SCHED(25), SNSUP, DIMF, METHOD, LINF,
**PE
REAL NCAR, MATINF, LABINF, LABORS
INTEGER POINT, YEAR, HIGH, LOW, PAYS
**TP
LEVEL=1
CALL PLOTS("GRF")
TYPE 10
FORMAT(" BR\AKING AND COUPLING"/,
**", "\ TYPE HELP FOR DIRECTIONS.")
TYPE 20
FORMAT(" INSTRUCTION"," A")
ACCEPT 40,ANS
40
FORMAT(AS)
IMATCH=0
IF(LEVEL.GT.2) LEVEL=2
CALL LOOK(1MATCH,ANS,LEVEL)
IF(ANS.EQ."STOP") GO TO 50
IF(1MATCH.EQ.0) GO TO 70
GO TO 20
50
TYPE 50
FORMAT(" ARE YOU FINISHED WITH THE PROGRAM? ", S)
ACCEPT 40,ANS
IF(ANS.NE."YES") GO TO 50
GO TO 60
50
FORMAT(" FINISHED. TURN ON PLOT "
**ER AND TYPE THE FOLLOWING:"/,
**"," "MODIFIED. TO CHANGE A PARAMETER TYPE ITS KEYWORD "//
**", "AFTER THE PROMPT. WHEN FINISHED TYPE STOP.")
TYPE 40
LEVEL=17
FORMAT(" CHANGE"," A")
ACCEPT 50,ANS
FORMAt(AS)
IF(ANS.EQ."DEPRE") GO TO 100
IF(ANS.EQ."LIMIT") GO TO 411!
IF(ANS.EQ."COMPA") GO TO 430
IF(ANS.EQ."NUMBE") GO TO 480
IF(ANS.EQ."ATTRI") GO TO 520
IF(ANS.EQ."FRACT") GO TO 550
IF(ANS.EQ."INVES") GO TO 580
IF(ANS.EQ."TAX") GO TO 610
IF(ANS.EQ."UNION") GO TO 630
IF(ANS.EQ."SAVE") GO TO 650
IF(ANS.EQ."OTHER") GO TO 670
IF(ANS.EQ."LOSE") GO TO 690
IF(ANS.EQ."INFLA") GO TO 720
IF(ANS.EQ."RATES") GO TO 760
IF(ANS.EQ."AXES") GO TO 840
IMATCH=0
CALL LOOK(1MATCH,ANS,LEVEL)
IF(ANS.EQ."STOP") RETURN 1
IF(1MATCH.EQ.0) TYPE 60
FORMAT(" PLEASE CHECK THE NAME YOU ENTERED. IT IS NOT/"
**"ON THE LIST. YOU MUST REENTER 
***OR TYPE STOP.")
GO TO 30
REREAD 80,ANS
IMATCH=0
CALL LOOK(1MATCH,ANS,LEVEL)
FORMAT(AS)
IF(1MATCH.EQ.0) TYPE 90
FORMAT(" PLEASE HELP FOR MORE INFORMATION")
GO TO (400,430,430,520,550,580,650,6)
**90,630,670
RETURN 1
C
C COMPUTE DEPRECIATION SCHEDULE
100 TYPE 110
110 FORMAT(’WHAT IS THE LIFETIME OF
** THE ASSET?’,$)
LEVEL=15
READ(S,129,ERR=70) LIFE
FORMAT(I3)
IF(LIFE.GT.1) GO TO 140
TYPE 130
130 FORMAT(’ THE LIFETIME MUST BE ON
**E OR MORE. PLEASE
**REENTER.’)
GO TO 100
140 TYPE 150
150 FORMAT(’ WHICH METHOD OF DEPRECI
**ATION DO YOU WANT
**TO USE?/ /
1, 1.10, ” STRAIGHT”’,25, ” STRAIGHT
** LINE”
2,” T10,” DOUBLE”,25, ” DOUBLE 
**DECLINING BALANCE”
3,” T10,” SUM”,25,” SUM OF YEAR
**S DIGITS”/, */ METH
**OD: ’ $)
ACCEPT 50, ANS
IF(ANS.EQ.”STRAI”) GO TO 170
IF(ANS.EQ.”DOUBL”) GO TO 190
IF(ANS.EQ.”SUM”) GO TO 240
IF(ANS.EQ.”STOP”) GO TO 165
IMATCH=0
CALL LOOK(IMATCH,ANS,LEVEL)
IF(IMATCH.EQ.1) GO TO 140
C
C PRINT ERROR MESSAGE SINCE ENTRY
**COULD NOT BE IDENT
**IFIED
TYPE 160
160 FORMAT(’ PLEASE TYPE STRAIGHT,DO
**UBLE, OR SUM.’)
GO TO 140
165 TYPE 166
166 FORMAT(’ THE DEPRECIATION SCHEDU
**LE HAS NOT BEEN CH
**ANGED.’)
C
C STRAIGHT LINE METHOD
170 METHOD=1
DO 190 I=1,25
SCHED(I)=1./LIFE
IF(LIFE.GT.1) SCHED(I)=0.0
CONTINUE
GO TO 300
C
C DOUBLE DECLINING BALANCE METHOD
C
C RATE OF DEPRECIATION IS TWICE TH
**AT OF STRAIGHT LIN
**E METHOD
190 PERC=2./LIFE
BALANC=1.0
DO 220 I=1,24
SCHED(I)=BALANC*PERC
BALANC=BALANC-SCHED(I)
SCHED(25)=BALANC
GO TO 300
C
C SUM OF YEARS DIGITS METHOD
METHOD=3
SUM=(LIFE**2+LIFE)/2
DO 250 I=1,25
SCHED(I)=FLOAT(LIFE-I+1)/SUM
IF(I.GT.LIFE) SCHED(I)=0.0
CONTINUE
GO TO 300
C
C SHOW SCHEDULE
SUM=0.0
TYPE 310
310 FORMAT(’ YEAR FRACTION WRITTEN
**OFF IN THAT YEAR’)
DO 330
1=1,25
SCHED(I)
FORMAT(2X 1 12,5X,F5.3)
SUM=SUM+SCHED(I)
FORMAT(2X’, TOTAL=’,F5.3,’/)
GO TO 310
C
C CHANGE TIME HORIZON
TYPE 410
410 FORMAT(’ FOR HOW MANY YEARS SHOU
**LD THE CASH FLOWS’
**,
1’ BE CALCULATED?’,$)
LEVEL=3
READ (S,420,ERR=70) LIMIT
FORMAT(I3)
IF(LIMIT.LT.1) GO TO 450
IF(LIMIT.GT.25) GO TO 450
GO TO 300
C
C CHANGE THE YEAR FLEET BECOMES CO
**MPATIBLE
TYPE 440
440 FORMAT(’ HOW MANY YEARS DOES
THE SYSTEM TAKE TO BE
**COME’
1,’ COMPATIBLE??’,$)
LEVEL=4
READ (S,420,ERR=70) ICOMP
IF(ICOMP.LT.0) GO TO 470
IF(ICOMP.GE.25) GO TO 470
GO TO 300
C
C NUMBER OF CARS IN THE SYSTEM
TYPE 490
490 FORMAT(’ HOW MANY CARS ARE IN TH
**E SYSTEM??’,$)
LEVEL=5
READ (S,500,ERR=70) NCAR
IF(NCAR.GT.0.) GO TO 30

C

ATTRITION RATE

TYPE 530

FORMAT(" WHAT FRACTION OF THE CARS HAVE TO BE REPLACED EACH YEAR?",$)

LEVEL=6

READ (5,500,ERR=70) ATTRAT

IF(ATTRAT.GE.0.0.AND.ATTRAT.LE.1.0) GO TO 30

TYPE 540

FORMAT(" THE ATTRITION RATE MUST BE BETWEEN ZERO AND ONE.")

GO TO 520

C

ORIGINAL COST AS FRACTION OF NEW COST

TYPE 560

FORMAT(" WHAT FRACTION OF RETROFIT COST IS REQUIRED FOR NEW PRODUCTION (PER CAR)?",$)

LEVEL=7

READ (5,500,ERR=70) XFRAC

IF(XFRAC.GE.0.0.AND.XFRAC.LE.1.0) GO TO 550

GO TO 33

SAVINGS SUBJECT TO UNION

TYPE 660

FORMAT(" WHAT IS THE INVESTMENT TAX CREDIT?")

LEVEL=9

READ (5,420,ERR=70) PAYSTP

IF(PAYSTP.GE.0.0.AND.PAYSTP.LE.1.0) GO TO 30

TYPE 710

FORMAT(" FOR HOW MANY YEARS WILL SAVINGS BE PAID TO THE UNION?")

LEVEL=10

READ (5,500,ERR=70) UPAYRT

IF(UPAYRT.GT.1.) UPAYRT=UPAYRT/100.0

GO TO 30

C

INFLATION RATES

TYPE 730

FORMAT(" WHAT IS THE INFLATION RATE FOR MATERIALS (IN PERCENT)?",$)

LEVEL=14

READ (5,500,ERR=70) MATINF

MATINF=1.0+(MATINF/100.0)

GO TO 30

C

RANGE OF DISCOUNT RATES TO BE US

TYPE 770

FORMAT(" WHAT IS THE MINIMUM DISCOUNT RATE (IN PERCENT)?",$)
LEVEL=16
READ (5,420,ERR=70) LOW
TYPE 780
FORMAT( "WHAT IS THE MAXIMUM DIS
**COUNT RATE (IN PER
**CENT)?",S )
READ (5,420,ERR=70) HIGH
I=HIGH-LOW
LOW=I
GO TO 790
800 TYPE 810
FORMAT(" PLEASE SPECIFY A WIDER
**RANGE.")
GO TO 760
820 TYPE 930
FORMAT(" PLEASE SPECIFY A NARROW
**ER RANGE (LESS THAN
1/25 PERCENTAGE POINTS).")
GO TO 760
840 C LABELS ON AXES
850 FORMAT(" WHAT IS THE NEW LABEL FOR
**THE X-AXIS?",/"
1/ MAXIMUM 19 CHARACTERS: ",S )
ACCEPT 860,XLABEL(1),XLABEL(2)
860 FORMAT(245)
TYPE 870
870 FORMAT(" WHAT IS THE NEW LABEL FOR
**THE Y-AXIS?",/"
1/ USE ; INSTEAD OF A CARRIAGE
**RETURN.
1/ MAXIMUM 40 CHARACTERS: ",S )
ACCEPT 861,YLABEL(I),I=I,40
880 TYPE 880
FORMAT(" THE NEW LABELS ARE:"/
** X-AXIS: ",2A5
" Y-AXIS: ",4A1/* ARE THESE CORRECT?",S )
ACCEPT 50,ANS
IF(ANS.NE."YES") GO TO 840
GO TO 30
END
SUBROUTINE CRE($,MATCH)
GENERATE A LINE OF DATA
DIMENSION X(26,2)
COMMON LINES,DATA(26,2,10),POINT
**(10),LABEL(10,2),W
**(10),LABEL(10,2)
1,YLABEL(40),XLABEL(2)
INTEGER POINT
MATCH=1
TYPE 10
FORMAT(" TYPE STOP TO TERMINATE
**ENTRY/"
1/ TYPE ERROR TO REENTER A NUMBER
**ER/"
I=0
I=I+1
20
IF(I.LE.10) TYPE 30,I
IF(I.GE.10) TYPE 40,I
FORMAT("+X",I2,"+")
FORMAT("+Y",I2,"+")
READ (5,50,ERR=100),X(I,1)
FORMAT(F10.3)
IF(I.LE.10) TYPE 60,I
IF(I.GE.10) TYPE 70,I
FORMAT("+Y",I2,"+")
READ (5,50,ERR=100),X(I,2)
TYPE 80,X(I,1),X(I,2)
80 FORMAT("+X",F10.3,2X,"Y",F10.3,**/)
IF(I.LE.26) GO TO 20
TYPE 90
FORMAT(" DATA VECTOR IS FULL "/
1/ NO MORE POINTS CAN BE PLOTTED
**ON THIS LINE")
GO TO 190
REREAD 110,ANS
FORMAT(A5)
I=I-1
IF(ANS.EQ."STOP") GO TO 190
CALL LOOK(IMATCH,ANS,LEVEL)
ASSUME ERROR NEEDS TO BE CORRECTED
TYPE 120
FORMAT(" TYPE STOP TO TERMINATE
**ENTRY/"
1/ X TO CORRECT AN X VALUE*/
1/ Y TO CORRECT A Y VALUE*/
3/ R TO RESUME NORMAL ENTRY)
TYPE 130
FORMAT(" X,Y,R OR STOP: ",S )
ACCEPT 110,ANS
J=0
IF(ANS.EQ."R") GO TO 29
IF(ANS.EQ."STOP") GO TO 190
IF(ANS.EQ."X") J=1
IF(ANS.EQ."Y") J=2
IF(J.EQ.0) GO TO 115
TYPE 140,ANS
FORMAT(" WHICH " ,A1," DO YOU WANT 
**TO CORRECT?",S )
READ (5,150,ERR=115) K
FORMAT(I2)
IF(K.LE.0) GO TO 170
IF(K.GT.I) GO TO 170
IF(K.EQ.I) GO TO 25
IF(J.EQ.0) GO TO 115
TYPE 140,ANS
FORMAT(" WHICH " ,A1," DO YOU WANT 
**TO CORRECT?",&S )
READ (5,150,ERR=115) X(K,J)
GO TO 125
TYPE 180,I
FORMAT(" MUST BE BETWEEN 1 AND 
**/12",PLEASE REENTER
**TER/"
GO TO 135
CLOSE ENTRY
TYPE 200
FORMAT(10X,"X",I10X,"Y")
DO 210 K=1,I
TYPE 220,K=X(K,1),X(K,2)
FORMAT(1X,I2,F10.3,5X,F10.3)
TYPE 240
FORMAT(" IS THIS CORRECT (YES OR 
**/NO)?",S )
ACCEPT 110,ANS
IF(ANS.EQ."NO") GO TO 115
IF(ANS.EQ."YES") GO TO 230
FILE DATA
LINES=LINES+1
POINT(LINES)=I
DO 250 J=1,2
DO 250 M=1,L
DATA(M,J,LINES)=X(M,J)
CALL LABEL($260,IMATCH)
RETURN 1
END

250

260

C PROVIDE INITIAL VALUES FOR PARAMETERS

C BLOCK DATA

C COMMON LINES,DATA(25,2,10),POINT
**=(10),LABEL(10,2)
**M,NCAR,ATTRAT,M
**W,LABEL(10,2)
**L,LABEL(10,2)
**R,R,LABEL(10,2)
**T,LABEL(10,2)
**V,LABEL(10,2)
**X,LABEL(10,2)
**Y,LABEL(10,2)
**Z,LABEL(10,2)

C INTEGER NCAR,MATINF,LABINF,LABORS

C REAL NCAR,MATINF,LABINF,LABORS

C COMMON LINES,DATA(25,2,10),POINT
**=(10),LABEL(10,2)
**M,NCAR,ATTRAT,M
**W,LABEL(10,2)
**L,LABEL(10,2)
**R,R,LABEL(10,2)
**T,LABEL(10,2)
**V,LABEL(10,2)
**X,LABEL(10,2)
**Y,LABEL(10,2)
**Z,LABEL(10,2)

C INTEGER POINT,YEAR,HIGH,LOW,PAYSTP

C REAL POINT,YEAR,HIGH,LOW,PAYSTP

C COMMON LINES,DATA(25,2,10),POINT
**=(10),LABEL(10,2)
**M,NCAR,ATTRAT,M
**W,LABEL(10,2)
**L,LABEL(10,2)
**R,R,LABEL(10,2)
**T,LABEL(10,2)
**V,LABEL(10,2)
**X,LABEL(10,2)
**Y,LABEL(10,2)
**Z,LABEL(10,2)

C INTEGER POINT,YEAR,HIGH,LOW,PAYSTP

C REAL POINT,YEAR,HIGH,LOW,PAYSTP

C DELETE A LINE FROM DATA AND COMP

C ERROR MESSAGE

C TYPE 4Q,LINES

C FORMAT(\"LINE NUMBER MUST BE BETWEEN 1 AND 12, \"")

C IF(ANS.EQ.\"STOP\") RETURN

C CALL LOOK(IMATCH,ANS,LEVEL)

C END

C SUBROUTINE DELET($,MATCH)

C COMMON LINES,DATA(25,2,10),POINT
**=(10),LABEL(10,2)
**M,NCAR,ATTRAT,M
**W,LABEL(10,2)
**L,LABEL(10,2)
**R,R,LABEL(10,2)
**T,LABEL(10,2)
**V,LABEL(10,2)
**X,LABEL(10,2)
**Y,LABEL(10,2)
**Z,LABEL(10,2)

C INTEGER POINT

C MATCH=I

C IF(LINES.GT.0) GO TO 5

C TYPE 2

C FORMAT(\" THERE ARE NO MORE LINES \"
** TO DELETE.\")

C RETURN 1

C TYPE 10,LINES

C FORMAT(\" THERE ARE NOW \"{12, LI

C NINES WHICH ONE DO \"

C YOU\")

C 1,\" WANT TO DELETE? TYPE PRINT T

C **SEE THE REMAINING **G DATA.\")

C 2,\" TYPE STOP WHEN FINISHED.\")

C 3,\" LINE:\"S)

C LEVEL=19

C READ (5,20,ERR=49).LINE

C FORMAT(13)

C IF(LINE.LT.1) GO TO 30

C IF(LINE.GT.LINES) GO TO 30

C IF(LINE.NE.LINES) GO TO 60

C LINES=LINES-1

C GO TO 1

C ERROR MESSAGE

C TYPE 4Q,LINES

C FORMAT(\"LINE NUMBER MUST BE BETWEEN 1 AND 12, \"")

C IF(ANS.EQ.\"STOP\") RETURN

C CALL LOOK(IMATCH,ANS,LEVEL)

C END

C SUBROUTINE GRA($1,MATCH)

C PLOT AXES, PLOT EACH LINE

C IN THE **MATRIX
DATA, LABEL EACH LINE, PLACE TITLE UNDER GRAPH

DIMENSION MIN(2), MAX(2), DIFF(2),
**TITLE(50), ISORT(10)
**,
1 MAG(2), ITICK(2), IDEL(2), XINC(2)
**, IDEC(2), SCALE(2),
**ISIG(2)

COMMON LINES, DATA(26, 2, 10), POINT
**(10), LABEL(10, 2), W
**IDTH(2)

LABEL(40), XLABEL(2)

REAL MIN, MAX,

DATA TITLEX/4.0/
DATA TITLEY/9.00/
DATA TITLE/50*/

Determine if there is plotting to be done
IF(LINES.LT.1) GO TO 170

Find minimum and maximum values
DO 50 J=1, 2
MAX(J)=DATA(I, J, 1)
MIN(J)=DATA(I, J, 1)
DO 10 K=LINES
IF(MIN(J).LT.DATA(I, J, K)) MIN(J)=DATA(I, J, K)
IF(MAX(J).GT.DATA(I, J, K)) MAX(J)=DATA(I, J, K)
10 CONTINUE

Find range for each axis and choose upper and lower bounds so that boundaries will be round numbers

DIFF(J)=MAX(J)-MIN(J)
A=DIFF(J)
IF(A.EQ.0.0) GO TO 120
IEXP=0
PTEN=1.0
IF(A.GE.1.0) GO TO 11
A=A/10.0
IEXP=IEXP+1
PTEN=PTEN/10.0
GO TO 12

IF(A.LT.10.0) GO TO 13
A=A/10.0
IEXP=IEXP+1
PTEN=PTEN/10
GO TO 12

MAG(J)=A*INT(A)

XINC IS THE INTERVAL BETWEEN SLATES ON THE AXES

XINC(J)=.25
IF(MAG(J).GE.2.0) XINC(J)=.5
IF(MAG(J).GE.4.0) XINC(J)=1.0
IF(MAG(J).GE.8.0) XINC(J)=2.0
XINC(J)=XINC(J)*PTEN
MIX=IFIX(MIN(J)/XINC(J)+.01)
MAN=IFIX(MAX(J)/XINC(J)-.01)
IF(MIN(J).LE.-99) MIX=MIX+1
IF(MAX(J).GE.99) MAN=MAN+1

X=AMAX1(ABS(MIN(J)), ABS(MAX(J)))
ISIG(J)=2+MAX0(0, INT(ALOG10(X)))+MAX0(0, IDEC(J))

COMPUTE SCALE FACTOR BASED ON THE GRAPH DIMENSIONS
IF(WIDTH(J).LT.1.0) GO TO 190
SCALE(J)=DIFF(J)/WIDTH(J)
CONTINUE

Find title for graph
TYPE 52
FORMAT(• DO YOU WANT A TITLE ON THIS GRAPH? ' $)
LEVEL=20
ACCEPT 55, ANS
FORMAT(A5)
IF(ANS.EQ."NO") GO TO 54
IF(ANS.EQ."YES") GO TO 345
CALL LOOK(IMATCH, ANS, LEVEL)
GO TO 51

TYPE 530
FORMAT(" HOW FAR ABOVE THE X-AXIS DO YOU WANT THE "
**1. TOP OF THE FIRST LINE TO BE **(IN INCHES, BETWEEN **1 AND 10")

2, $)
READ (5, 330, ERR=400) TITLEY
FORMAT(E10.0)
TYPE 330
FORMAT(" HOW FAR TO THE RIGHT OF ** THE Y-AXIS DO YOU WANT "
**1. " THE LEFT HAND EDGE OF THE **TITLE (BETWEEN 0 A **AND 6) " $)
READ (5, 330, ERR=400) TITLEX
TYPE 340
FORMAT(" THE TITLE WILL BE " F4. **1.shima above t **5E X-AXIS",
**1. AND " F4. **1. inches to the r **right of the Y-AXIS " )
Provide user instructions at various points of the program.

Subroutine HELP(S, MATCH, LEVEL)

MATCH = 1
GO TO (2, 40, 80, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 230, 250, 270, 290) LET

IF LEVEL = 0, NO MORE INFORMATION AVAILABLE
**N IS AVAILABLE

TYPE 10
FORMAT(’ THERE IS NO MORE INFORMATION AVAILABLE’)
1, ’FOR THIS SECTION.’ )
RETURN 1

MODEL HAS NOT YET BEEN CALLED

TYPE 30
FORMAT(’ THIS PROGRAM CONTAINS A NUMBER OF SUBPROGRAMS’)
1, ’TO PERFORM SPECIFIC TASKS.’
2, ’USE THE KEYWORD FOR THAT TASK.’
3, ’KEYWORD’T20,’FUNCTION’
4, ’HELP,’T14,’INFORMATION ABOUT A PARTICULAR OPERATIONAL QUESTION’
5, ’MODEL,’T14,’SET PARAMETERS’
6, ’AND COUPLING MODEL’
7, ’CHANGE,’T14,’CHANGE SPECIFIC PARAMETERS IN THE MODEL’
8, ’SOLVE,’T14,’SOLVE FOR AVAILABLE DOLLARS PER CAR’
9, ’AND STORE THE RESULTS’
10, ’VARIABLE,’T14,’SOLVE FOR DOLLARS PER CAR WITH’
11, ’T14,’SOLVE FOR SAVINGS OVER TIME’
12, ’VARIABLE SAVINGS OVER TIME’
13, ’GRAPH,’T14,’PLOT THE DATA IN THE FILE’
14, ’PRINT,’T14,’PRINT THE DATA IN THE FILE’
15, ’LIST,’T14,’THE PARAMETERS AND THEIR VALUES IN THE MODEL’
16, ’DELETE,’T14,’REMOVE ONE OR MORE LINES FROM THE DATA FILE’
17, ’CREATE,’T14,’ENTER A LINE INTO THE FILE’

TYPE 35
FORMAT(’ THIS PROGRAM WILL NOW ** AUTOMATICALLY ENTER **ER MODEL’
6, ’AND THEN LIST,’T14,’ YOU CAN ** THEN USE CHANGE TO ** CORRECT’
7, ’ANY ERRORS. THEN TYPE SOLVE F ** FOLLOWED,’T14,’BY PR **INT OR GRAPH.’

<table>
<thead>
<tr>
<th>C IF STILL OUT OF ORDER RETURN FOR ANOTHER PASS</th>
<th>C IF(IDONE.EQ.0) GO TO 110</th>
</tr>
</thead>
<tbody>
<tr>
<td>135 X=WIDTH(1)*.75</td>
<td>140 X=WIDTH(l) +.15</td>
</tr>
<tr>
<td>YJ=0.1</td>
<td>YJ=J.T0.2</td>
</tr>
<tr>
<td>DO 150 IBUBLE=1,LINES</td>
<td>DO 155 I=1,50</td>
</tr>
<tr>
<td>LINE=ISORT(IBUBLE)</td>
<td>IF(TITLE(I).NE.&quot;;&quot; ) GO TO 152</td>
</tr>
<tr>
<td>Y=DATA(IEND(LINE),2,LINE)/SCALE( **2)-YZERD-0.1</td>
<td>X=TITLEX</td>
</tr>
<tr>
<td>CHECK FOR OVERWRITE</td>
<td>IF(TITLE(I).NE.&quot;;&quot; ) GO TO 152</td>
</tr>
<tr>
<td>IF(IBUBLE.EQ.1) GO TO 140</td>
<td>IF(TITLE(I).NE.&quot;;&quot; ) GO TO 152</td>
</tr>
<tr>
<td>JBUBLE=IBUBLE-1</td>
<td>CALL SYMBOL(WIDTH(l),Y,15,LABEL(LINE,1),fll.15,1)</td>
</tr>
<tr>
<td>JLINE=ISORT(JBUBLE)</td>
<td>X=X+2</td>
</tr>
<tr>
<td>MOVE LABEL UP IF IT WILL OVERRITE PREVIOUS LABEL</td>
<td>CONTINUE</td>
</tr>
<tr>
<td>YJ=Y</td>
<td>Y=DATA(IEND(LINE),2,LINE)/SCALE( **2)-YZERD-0.1</td>
</tr>
<tr>
<td>IF(YJ.GT.2) GO TO 140</td>
<td>PUT TITLE UNDER GRAPH</td>
</tr>
<tr>
<td>Y=Y+0.2-YJ</td>
<td>YJ=Y</td>
</tr>
<tr>
<td>CONTINUE</td>
<td>CONTINUE</td>
</tr>
<tr>
<td>PUT LABEL NEXT TO ENDPOINT</td>
<td>PUT LABEL NEXT TO ENDPOINT</td>
</tr>
<tr>
<td>IF(LABEL(LINE,1).EQ.&quot; &quot;) GO TO 145</td>
<td>IF(LABEL(LINE,1).EQ.&quot; &quot;) GO TO 145</td>
</tr>
<tr>
<td>CALL SYMBOL(WIDTH(l),Y,0.15,LABEL **(LINE,1),0.0,5)</td>
<td>CALL SYMBOL(WIDTH(l),Y,0.15,LABEL **(LINE,1),0.0,5)</td>
</tr>
<tr>
<td>IF(LABEL(LINE,1).EQ.&quot; &quot;) GO TO 145</td>
<td>IF(LABEL(LINE,1).EQ.&quot; &quot;) GO TO 145</td>
</tr>
<tr>
<td>CALL SYMBOL(X,Y,0.15,LABEL(LINE,2), **0.3,0.5)</td>
<td>CALL SYMBOL(X,Y,0.15,LABEL(LINE,2), **0.3,0.5)</td>
</tr>
<tr>
<td>145 YJ=Y</td>
<td>150 CONTINUE</td>
</tr>
<tr>
<td>150 CONTINUE</td>
<td>160 TYPE 161</td>
</tr>
<tr>
<td>161 FORMAT(’ TYPE YES IF YOU ARE FINISHED WITH THE’/</td>
<td>162 FORMAT(’ PRINT,’T14,’PRINT THE DATA IN THE FILE’</td>
</tr>
</tbody>
</table>
| 1,” DATA JUST GRAPHED. TYPE NO IF **F YOU WISH TO”/
| 2,” USE IT AGAIN. CLEAR DATA?”/ $** )
| ACCEPT 162,ANS | ACCEPT 162,ANS |
| 162 FORMAT(A3) | IF(ANS.EQ."NO") GO TO 165 |
| IF(ANS.EQ."YES") GO TO 165 |
| 165 RETURN 1 |
| 170 TYPE 180 |
| 180 FORMAT(’ THERE ARE NO LINES TO PLOT’ ) |
| RETURN 1 |
| 190 TYPE 200 |
| 200 FORMAT(’ WIDTH IS TOO SMALL. PLEASE CORRECT’ ) |
| RETURN 1 |
| END |
**NOTE THAT PRINT AND GRAPH**

**WILL OUTPUT ALL TH**

**E SOLUTIONS**

**MADE UP TO THAT TIME. PART**

**SOLU TION S C**

**AN BE REMOVED**

**WITH DELETE**/

CALL MODEL($36,IMATCH,LEVEL)

LEVEL=2

RETURN 1

**INSTRUCTION HE L P**

TYPE 30

TYPE 50

**IF THERE ARE any PAR AM E**

**ERS THAT NEED TO**

1." BE CHANGED TYPE CHANGE/"/

**OTHERWISE TYPE So**

**LVE.**

2." YOU WILL BE ASKED FOR A LA**

**BEL THAT WILL**

3." BE PRINTED NEXT TO THE DATA**

**JUST/" OBTAINED**

**.**

4." THEN YOU MAY CHANGE THE PARA**

**METERS TO CONSTRUC**

**T A NEW**

5." MODEL. THERE MAY BE UP**

**TO TEN LINES ON THE GRAPH.**

LEVEL=0

RETURN 1

**LIFETIME OF THE ASSET (MODEL,CHANGE)**

TYPE 70

**THE DEPRECIATION SCHEDU**

**LE IS BASED ON**

1." THE LIFETIME ASSIGNED TO THE**

**/",/ EQUIPMENT**

2." YOUR ANSWER SHOULD BE AN INT**

**GER BETWEEN 1 AND**

**99**

RETURN 1

**TIME HORIZON**

TYPE 90

**THE FIRST CASH FLOW WILL**

**BE ASSUMED TO BE**

1." IN YEAR ONE. YOUR"/

**RESPOND**

**SHOULD BE BETWEEN**

**1 AND 26**

2." CASH FLOWS OCCURRING AFTER TH**

**IS**

1." LIMIT WILL BE IGNORED**

RETURN 1

**COMPATIBLE**

100

RETURN 1

110

RETURN 1

120

RETURN 1

**LABEL THE LAST LINE GENERATED**
SUBROUTINE LABL($1,MATCH)  
COMMON LINES,DATA(26,2,10),POINT  
**$(10),LABEL(10,2)  
INTEGER POINT  
MATCH=1  
10 TYPE 20  
20 FORMAT(" LABEL (MAXIMUM 10 CHARA  
**CTERS):",$)  
ACCEPT 20,LABEL(LINES,1),LABEL(L  
**INES,2)  
30 TYPE 2A5  
40 TYPE 50,LABEL(LINES,1),LABEL(LIN  
**ES,2)  
50 FORMAT(1X,2A5,"IS THE LABEL C  
**ORECT?",$)  
ACCEPT 60,ANS  
60 FORMAT(A5)  
IF(ANS.EQ."NO") GO TO 10  
IF(ANS.EQ."YES") GO TO 40  
70 IF(LINES.NE.1) TYPE 70,LINES  
70 IF(LINES.EQ.1) TYPE 80  
80 FORMAT(" THERE IS NOW 1 LINE ON  
**THE GRAPH.")  
RETURN 1  
END  
C C C 
LIST THE PARAMETERS AND THE CURR  
**ENT VALUE OF EACH  
SUBROUTINE LIST($1,MATCH)  
COMMON LINES,DATA(26,2,10),POINT  
**$(10),LABEL(10,2),W  
**IDTH(2)  
1,YLABEL(40)XLABEL(2),LIMIT,ICO  
**MP,NCAR,ATTRAT,M  
**ATINF  
2,LABINF,LABORS,L0W,HIGH,PAYSTP,  
**PRAC,FRIDT,FRAC,FRIDT,FRAC  
**UPAYRT  
3,SCHED(25),SNSUP,OINF,METHOT,LI  
**FE  
REAL NCAR,MATINF,LABINF,LABORS  
INTEGER POINT,YEAR,HIGH,LW,PAVS  
**TP  
MATCH=1  
10 TYPE 10  
20 FORMAT(" VARIABLE",T37,"KEYWORD"  
**",T55,"CURRENT VALU  
**E")  
TYPE 20,LIMIT,ICOMP,NCAR,ATTRAT,  
**FRAC,FRIDT,TAXRAT  
20 FORMAT(" NUMBER OF YEARS IN ANAL  
**YS IS",T38,"LIMIT",  
**",T53,I2,"  
1," YEARS BEFORE SYSTEM IS COMPA  
**IBLE",T38,"COMPAT  
**ible",T53,I2,"  
2," NUMBER OF CARS",T38,"NUMBER",  
**",T55,F14.3,"  
3," ATTRITION RATE",T38,"ATTRITI  
**ON",T55,F14.3,"  
4," NEW COST OF EQUIPMENT",T38,  
**FRACTI",T55,F14.  
**3,"  
5," INVESTMENT TAX CREDIT",T38,  
**INVESTMENT",T55,F1  
**4.3,"  
**3)  
TYPE 30,UPAYRT,LABORS,PAYSTP,SN  
**UP,MATINF,LABINF,U  
**INF  
FORMAT(" LOSS TO UNION",T38,"UNI  
**ON",T55,F14.3,"  
1," LABOR SAVINGS",T38,"SAVINGS",  
**",T55,F14.3,"  
2," YEARS SAVINGS ARE LOST TO UN  
**ON",T38,"LOSE",T6  
**3,12,"  
7," OTHER SAVINGS",T38,"OTHER",T  
**55,F14.3,"  
3," INFLATION",T38,"INFLATION",  
**")  
4,T8,"MATERIALS",T55,F14.3,"  
5,T8,"LABOR",T55,F14.3,"  
6,T8,"OTHER",T55,F14.3")  
TYPE 40,LOW,HIGH,LIFE  
FORMAT(" MINIMUM DISCOUNT RATE",  
**",T38,"RATES",T63,I2  
**")  
1," MAXIMUM DISCOUNT RATE",T38,  
**",RATES",T63,I2,"  
2," DEPRECIATION",T38,"DEPRECIAT  
**",T63,I2,"  
3,T8,"LIFETIME OF ASSETS",T63,I  
**",/8X,$)  
IF(METHOT.EQ.1) TYPE 50  
IF(METHOT.EQ.2) TYPE 60  
IF(METHOT.EQ.3) TYPE 70  
FORMAT(" STRAIGHT LINE",$)  
FORMAT(" DOUBLE DECLINING BALANC  
**E")  
FORMAT(" SUM OF YEARS DIGITS",$)  
TYPE 88  
FORMAT(" DEPRECIATION USED",$)  
TYPE 90,XLABEL(1),XLABEL(2),YLA  
**BEL(1),I=1,40  
FORMAT(" THE AXES ARE LABELED AS  
**FOLLOWS:"/)  
1," X-AXIS:","2A5.5X,"Y-AXIS:  
**",/40A1,/,20X,"KEYWD  
**",/D IS AXES")  
RETURN 1  
END  
C C C  
LOOK FOR COMMAND THAT MATCHES TH  
**E INPUT  
SUBROUTINE LOOK(IMATCH,ANS,LEVEL  
**")  
IF(ANS.EQ."CREA") CALL CRE($1A,  
**MMATCH)  
IF(ANS.EQ."GRAP") CALL GRA($1A,  
**MMATCH)  
IF(ANS.EQ."CHANG") CALL CHANG($1  
**MMATCH)  
IF(ANS.EQ."DELET") CALL DELET($1  
**MMATCH)  
IF(ANS.EQ."PRINT") CALL PRINT($1  
**MMATCH)  
IF(ANS.EQ."SOLVE") CALL SOLVE($1  
**MMATCH)  
RETURN 1  
END
IF(ANS.EQ."HELP") CALL HELP($10,**IMATCH,LEVEL)
IF(ANS.EQ."LIST") CALL LIST($10,**IMATCH)
IF(ANS.EQ."TRACE") CALL TRACE
IF(ANS.EQ."NULL") IMATCH=1
IF(ANS.EQ."MODEL") CALL MODEL($1,**IMATCH,LEVEL)
IF(ANS.EQ."VARIA") CALL VARIA($1,**IMATCH)
IF(ANS.EQ."VARU") CALL VARU($1,**IMATCH)
RETURN
ANS="NULL"
IMATCH=1
RETURN
END

CONSTRUCT A SET OF PARAMETERS FROM SCRATCH

SUBROUTINE MDDEL($,MATCH,LEVEL)
COMMON LINES,OATA(26,2,10),POINT**(10),LABEL(10,2),**IOTH(2)
1,YLABEL(40),XLABEL(2)
LIMIT,ICO**MP,X,NCAR,ATTRAT,M** ATINF
2,LABINF,LABORS,LOW,HIGH,PAYSTP,**FRAC,FRIDT,TAXRAT,**UPAYRT,3SCHED(25),SNSUP,OINF,METHOD,LIF**E
REAL NCAR,MATINF,LABINF,LABORS
INTEGER POINT,YEAR,HIGH,LOW,PAYS**TP
MATCH=1

TYPE HEADING

FORMAT(" THIS IS A MODEL TO ESTIMATE THE AMOUNT THAT CAN BE SPENT PER FREIGHT CAR FOR **ADVANCED BRAKING"**/
**/ AND COUPLING.")
GO TO 21

ERROR PROCEDURE

REREAD 12,ANS
IMATCH=0
CALL LOOK(1,ANS,LEVEL)
FORMAT(15)
IF(1,ANS.EQ."STRAI") TYPE 11
IF(1,ANS.EQ."DOUBL") GO TO 19
IF(1,ANS.EQ."SUM") GO TO 249
PRINT ERROR MESSAGE SINCE ENTRY COULD NOT BE IDENTIFIED
FORMAT(" PLEASE TYPE STRAIGHT, DOUBLE, OR SUM")
GO TO 140

PRINT ERROR MESSAGE SINCE ENTRY COULD NOT BE IDENTIFIED

GO TO 140

STRAIGHT LINE METHOD
METHOD=1
DO 150 I=1,25
SCHED(I)=1.0/FLOAT(LIFE)
IF(I.GT.LIFE) SCHED(I)=0.
GO TO 150

RETURN 1
CONTINUE
GO TO 300

DOUBLE DECLINING BALANCE METHOD

RATE OF DEPRECIATION IS TWICE THAT OF STRAIGHT LINE METHOD

METHOD=2
PERC=2.0/FLOAT(LIFE)
BALANC=1.0
DO 220 I=1,24
SCHED(I)=BALANC*PERC
BALANC=BALANC-SCHED(I)
SCHED(25)=BALANC
GO TO 300

SUM OF YEARS DIGITS METHOD

METHOD=3
SUM=(LIFE**2+LIFE)/2
DO 250 I=1,25
SCHED(I)=FLOAT(LIFE-I+1)/SUM
IF(I.GT.LIFE) SCHED(I)=0.0
CONTINUE
GO TO 300

SHOW SCHEDULE

SUM=0.0
TYPE 310
FORMAT(" YEAR FRACTION WRITTEN **OFF IN THAT YEAR")
DO 330 I=1,25
TYPE 320 I
SCHED(I)
FORMAT(2X,I2,5X,F5.3)
SUM= SUM+SCHED(I)
TYPE 340,SUM
FORMAT(//' TOTAL=',F5.3,//)
GO TO 34

CHANGE TIME HORIZON

TYPE 410
FORMAT(" FOR HOW MANY YEARS SHOULD THE CASH FLOWS** BE CALCULATED?",$)
LEVEL=3
READ (5,420,ERR=10) LIMIT
FORMAT(13)
IF(LIMIT.LT.1) GO TO 450
IF(LIMIT.GT.26) GO TO 450
GO TO 22

CHANGE THE YEAR FLEET BECOMES Compatible

TYPE 440
FORMAT(" HOW MANY YEARS DOES THE SYSTEM TAKE TO BE **COMPATIBLE?",$)
LEVEL=4
READ (5,420,ERR=10) ICOMP
IF(ICOMP.LT.0) GO TO 470
IF(ICOMP.GE.25) GO TO 470
GO TO 23

TYPE 460
FORMAT(" YEAR MUST BE BETWEEN 0 **AND 25, PLEASE REI **NTER.")

NUMBER OF CARS IN THE SYSTEM

TYPE 490
FORMAT(" HOW MANY CARS ARE IN THE **SYSTEM?",$)
LEVEL=5
READ (5,500,ERR=10) NCAR
FORMAT(18,0)
IF(NCAR.GT.0.0) GO TO 24
TYPE 510
FORMAT(" THERE HAS TO BE MORE THAN **AN ZERO CARS.")
GO TO 480

ATTRITION RATE

TYPE 530
FORMAT(" WHAT FRACTION OF THE CARS HAVE TO BE REPLACED EACH YEAR?",$)
LEVEL=6
READ (5,500,ERR=10) ATTRAT
IF(ATTRAT.GE.0.0.AND.ATTRAT.LE.1 **.0) GO TO 25
TYPE 540
FORMAT(" THE ATTRITION RATE MUST BE BETWEEN ZERO AND ONE.")
GO TO 520

ORIGINAL COST AS FRACTION OF NEW COST

TYPE 560
FORMAT(" WHAT FRACTION OF RETROFIT **IT COST IS REQUIRED FOR",$)
LEVEL=7
READ (5,500,ERR=10) FRAC
XFRAC=FRAC*100.0
TYPE 570,XFRAC
FORMAT(" FRACTION=",F6.1,$)
LEVEL=8
READ (5,500,ERR=10) FRIDT
IF(FRIDT.GE.0.0) GO TO 32
TYPE 580
FORMAT(" FRACTION CANNOT BE LESS THAN ZERO.")
GO TO 580

TAX RATE

TYPE 620
FORMAT(" WHAT IS THE INVESTMENT TAX CREDIT?",$)
LEVEL=13
READ (5,500,ERR=10) FRTD
IF(FRTD.GE.0.0) GO TO 32
TYPE 660
FORMAT(" FRACTION CANNOT BE LESS THAN ZERO.")
GO TO 580

TAX RATE

TYPE 620
FOR WHAT IS THE TAX RATE FOR THE RAILROAD INDUSTRY?

LEVEL=12
READ (5,500,ERR=10) TAXRAT
IF (TAXRAT.GT.1.D0) TAXRAT=TAXRAT/10**0.
GO TO 31

UNION PAYOFF RATE
TYPE 640
FORMAT(" WHAT FRACTION OF LABOR **SAVINGS ARE PAID" 1., " TO THE UNION?", $)
LEVEL=10
READ (5,500,ERR=10) UPAYRT
IF (UPAYRT.GT.1.) UPAYRT=UPAYRT/1
GO TO 29

SAVINGS SUBJECT TO UNION
TYPE 680
FORMAT( " WHAT IS THE LABOR SAVINGS PER YEAR THAT I ***", 1., " SUBJECT TO UNION PAYOUT?", $)
LEVEL=8
READ (5,500,ERR=10) LABORS
GO TO 27

SAVINGS NOT SUBJECT TO UNION PAY OFF
TYPE 700
FORMAT( " FOR HOW MANY YEARS WILL ** SAVINGS BE PAID TO THE UNION?" 1.), LEVEL=9
READ (5,500,ERR=10) SNSUP
GO TO 30

STOP PAYING OFF UNION
TYPE 710
FORMAT( " THERE MUST BE BETWEEN 2 **BRO AND 12, " VEA **RS. " )
GO TO 690

INFLATION RATES
TYPE 730

FORMAT( " WHAT IS THE INFLATION RATE FOR: / 1., " MATERIALS (IN PERCENT)?", $)
LEVEL=14
READ (5,500,ERR=10) MATINF
MATINF=1.+(MATINF/100.)
TYPE 740
FORMAT(" *LABOR (IN PERCENT)?", $)
READ (5,500,ERR=10) LABINF
LABINF=1.+(LABINF/100.)
TYPE 750
FORMAT(" *SAVINGS NOT SUBJECT TO **UNION PAYOUT" 1., " (IN PERCENT)?", $)
READ (5,500,ERR=10) OINF
OINF=1.+(OINF/100.)
GO TO 33

PRINT THE CONTENTS OF DATA
SUBROUTINE PRINT($,MATCH)
COMMON LINES,DATA(26,2,10),POINT **(10),LABEL(10,2),WIDTH(2)
**MATCH(2),YLABEL(4111),XLABEL(2)
REAL NCAR,MATINF,LABINF,LABORS
INTEGER POINT,YEAR,HIGH,LOW,PAYSTP
MATCH=1
DO 30 LINE=1, LINES
TYPE 10,LINES,LABEL(LINE,1),LABEL **(LINE,2),
1,XLABEL(2),LIMIT,ICOMP **MP,X,NCAR,ATTRAT,**AMP **MATINF
2,LABINF,LABORS,LOW,HIGH,PAYSTP,**FRAC,PRIDT,TAXRAT,**UPAYRT
3,SCHED(25),SNSUP,OINF,METHOD,LI **FE
REAL NCAR,MATINF,LABINF,LABORS
INTEGER POINT,YEAR,HIGH,LOW,PAYS **TP
MATCH=1
DO 30 LINE=1, LINES
TYPE 10,LINES,LABEL(LINE,1),LABEL **(LINE,2)
1,XLABEL(2),LIMIT,ICOMP **MP,X,NCAR,ATTRAT,**AMP **MATINF
10, I=1,480
FORMAT(" LINE NUMBER: " I2,T2 **0,"LABEL: ",2A5
1,/,8X,2AS,2X,4@A1)
DO 30 I=1,PIN LINES
TYPE 20,1,LINES,DATA(I,1,LINE),DATA(I, **2,LINES),
FORMAT(1X,I2,5X,F10.3,2X,F10.3) CONTINUE RETURN 1 END

GIVEN PARAMETERS FIND THE AMOUNT** WHICH CAN BE SPENT ** PER CAR FOR A VARIETY OF DISCOUNT RA **TEES. STORE THE RES **ULTS
SUBROUTINE SOLVE($,MATCH)
DIMENSION A(26),B(26),START(26), **ANNUAL(26),TAXCR(2 **6)
**DEPR(T) **

**OTHER(26), SAVING(26)**

**COMMON LINES, DATA(26, 2, 10), POINT**

**IF**(10) **L** **LABEL(10, 2)** **W**

**IDTH(2)**

**V** **L** **LABEL(48), XL** **LABEL(2), LIMIT, ICO**

**MP(1), NCAR, ATTR, M**

**ATINF**

**LABINF, LABORS, LOW, HIGH, PAYSTP, **

**FRAC, FRIOT, TAXRAT,**

**UPAYRT**

**SCHED(25), M** **SUP(1), INT, METHOD, L**

**FS**

**REAL NCAR, MATINF, LABINF, LABORS**

**INTEGER POINT, YEAR, HIGH, LOW, PAYS**

**TP**

**MATCH=1**

**C**

**COMPUTE CASH FLOWS FOR EACH YEAR**

****

**PER DOLLAR OF RETROFIT COST**

**C**

**CASH FLOWS IN YEAR = AX+B WHERE**

**C**

**SUM OF PER DOLLAR COST CASH FLOWS**

**A(YEAR)=START(YEAR)+ANNUAL(YEAR)**

**+TAXCR(YEAR)+DEPRT(YEAR)**

**B(YEAR)=SAVING(YEAR)+OTHER(YEAR)**

**FILE RESULTS**

**ROW=1-LOW+1**

**DATA(ROW,1,LINES)=I**

**XX=0.0-SUMB/SUMA**

**INT Y=AX+B WHERE**

**SUMA=START(YEAR)+ANNUAL(YEAR)**

**+TAXCR(YEAR)+DEPRT(YEAR)**

**SUMB=SAVING(YEAR)+OTHER(YEAR)**

**CONTINUE**

**COMPUTE PAYBACK PERIOD**

**CUME=0.0**

**DO 400 I=1,LIMIT**

**CUME=CUME+XX*A(I)+B(I)**

**IF(CUME.GE.X)**

**GO TO 400**

**CONTINUE**

**TYPE 405**

**FORMAT(’PAYBACK NOT REACHED.’)**

**RETURN**

**TYPE 420, I**

**FORMAT(’PAYBACK REACHED ’**

**’ YEARS AFTER START-**

**’UP.’)**

**RETURN**

**RETURN**

**TYPE 320**

**FORMAT(’DATA FILE IS FULL.’)**

**RETURN 1**

**END**
SOLVE WITH VARIABLE CASH FLOWS

SUBROUTINE VARIOUS($MATCH)

DIMENSION A(26),B(26),START(26),
**ANNUAL(26),TAXCR(2
**6)

1,DEPRT(26),OTHER(26),SAVING(26)

COMMON LINES,DATA(26,2),START,
**IDTH(2)

1,YLABEL(40),XLABEL(2),LIMIT,ICO

**MP,NCAR,ATTRAT,M
**ATINF

2,LABINF,LABORS,HIGH,PAYSTP,
**FRAC,FRIDT,TAXRAT,
**UPAYRT

1,SCHED(25),SNSUP,DINF,METHOD,LI

REAL NCAR,INATION,LABINF,LABORS
**PAYSTP.

DATA SAVING/30.,60.,90.,120.,150
**.

DATA OTHER/1.,2.,2.,3.,4.,5.,6.,7.,8.
**.

MATCH=1

COMPUTE CASH FLOWS FOR EACH YEAR
**PER DOLLAR OF Retrofit Cost

TAXCR(1)=0.0

IF(LINES.GE.10) GO TO 310

LINES=LINES+1

DO 100 YEAR=1,LIMIT

IF(YEAR.LE.PAYSTP) UNION=1.0

IF(YEAR.LE.PAYSTP) UNION=1.0-UPA
**YRT

SAVING(YEAR)=SAVING(YEAR)*10000
**

SAVING(YEAR)=SAVING(YEAR)*(1.0-T
**AXRAT)*UNION

1*(LABINF**(YEAR-1))

C SAVINGS NOT SUBJECT TO UNION PAY
**OFF

OTHER(YEAR)=OTHER(YEAR)*(1.0-TAX
**RAT)*(DINF**(YEAR-
**1))

C FIND SUM OF PER COST CASH FLOWS

A(YEAR)=START(YEAR)+ANNUAL(YEAR)
**+TAXCR(YEAR)+DEPRT
***(YEAR)

C FIND SUM OF FIXED FLOWS

B(YEAR)=SAVING(YEAR)+OTHER(YEAR)

C CASH FLOWS IN YEAR = AX+B WHERE
**X=COST OF RETROFIT
**TING ONE CAR

CONTINUE

C FIND PRESENT VALUE OF A AND B FROM
**ALL DISCOUNT RATES

DO 300 I=LOW,HIGH

SUMA=0.0

SUMB=0.0

R=1.0+FLOAT(I)/100.0

DO 299 YEAR=1,LIMIT

FACTOR=R**(YEAR-1)

SUMA=SUMA+A(YEAR)/FACTOR

SUMB=SUMB+B(YEAR)/FACTOR

CONTINUE

FILE RESULTS

ROW=I-LOW+1

DATA(ROW,1,LINES)=I

DATA(ROW,2,LINES)=-1*SUMB/SUMA

CONTINUE

POINT(LINES)=HIGH-LOW+1

RETURN

TYPE 320

FORMAT(‘* DATA FILE IS FULL.‘)

RETURN

END
REFERENCES


