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

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NOTICE

NOTICE

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16. Abstract

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.

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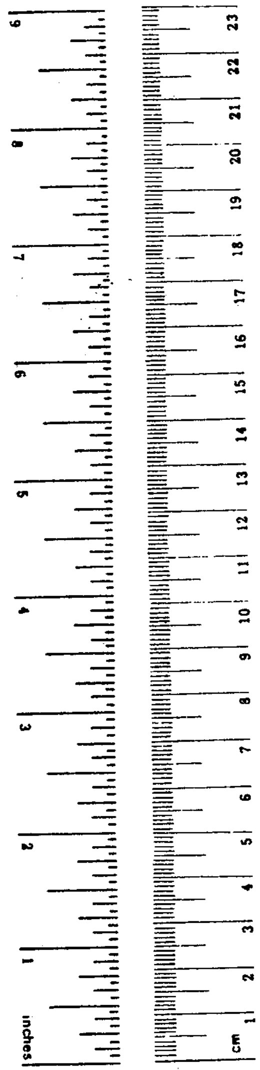
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

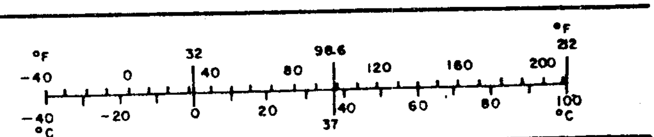
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

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.)

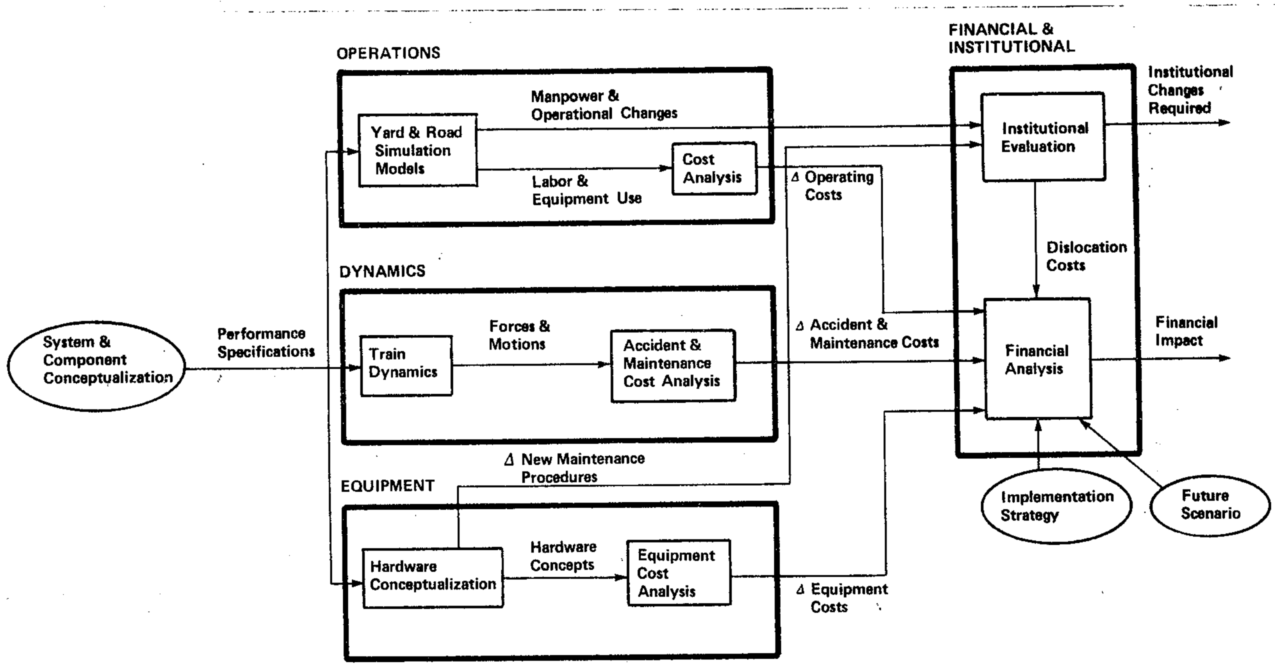


FIGURE E.1. OVERVIEW OF METHODOLOGY.

TABLE E.1. CANDIDATE SYSTEMS FOR EVALUATION

	Area of Improvement: Operations	Area of Improvement: Dynamics
Mechanical	• Knuckle-opener • Coupler centering device • Automatic air line connector • Incompatible coupler	• Truck-mounted brakes • Disk brakes • E couplers with shelves • High-strength couplers • Zero-slack couplers
Electrical	• Electrical connector • Locomotive-controlled couplers • Automatic brake bleed • Locomotive-designated car brakes • Ultrasonic brake control • Train condition monitor	• Load sensor • Radio controlled brake link • Electropneumatic brake • Electronic brake

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 extrapoliations 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 data bases 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

- ABDW 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
- Manual angle cock.

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 ABDW valves. Through attrition, the population will change slowly to ABDW 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 ABDW 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 ABDW, valve. Modifying the program to include the ABDW 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

Improved Operations — Mechanical Components

1. *Knuckle Open* — Knuckle is automatically opened upon disengagement from mating coupler.
2. *Coupler Centering* — When uncoupled, coupler is aligned with the carbody centerline.
3. *Automatic Air Line Connector* — Automatically connects train air line during mechanical coupling. Includes optional feature of closing airline when deliberately uncoupled.
4. *Incompatible Coupler* — 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.

Improved Operations — Electrical Components

5. *Electrical Connector* — Automatic or manual device that connects one or several electrical train lines.
6. *Locomotive-Controlled Coupler* — 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.
7. *Automatic Bleed* — Allows brake cylinder or reservoir or both to be gang bled from a remote location.
8. *Locomotive-Designated Car Brakes* — 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.
9. *Ultrasonic Brake Control* — 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.
10. *Train Condition Monitor* — 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.

Improved Dynamics — Alternative Mechanical Components

11. *Truck-Mounted Brakes* — Brake cylinders are mounted on trucks rather than carbody. Examples are WABCOPAC and NYCOPAC.
12. *Disk Brakes* — Provide disk braking surfaces instead of or in addition to conventional tread brakes.
13. *E Couplers With Shelves* — Provide interlocking shelves on standard E coupler to prevent vertical disengagement.
14. *High-Strength Couplers* — Couplers manufactured from high-strength steel to mitigate failure under heavy loads.
15. *Zero Slack Systems* — Couplers and draft gear with no slack to minimize run-out and run-in forces.

Improved Dynamics — Electrical Components

16. *Load Sensor* — Allows the application of a braking force that is proportional to the weight of the car.
17. *Radio-Controlled Brake Link* — A remote, radio-controlled brake initiation point located in a caboose or radio controlled locomotive.
18. *Electropneumatic Brakes* — Provide an electrical brake signal to a pneumatic brake system using passenger service technology.
19. *Electronic Brakes* — An electronic logic network that develops a brake command signal for an electropneumatic control valve.

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

		Operations		Dynamic Effects					Equipment			Financial & Institutional	
					In-Train Forces					Costing			
		Yard Operational Modeling	Local Road Operational Modeling	Train Collision and Derailment	Train Delay	Derailment and Broken Train Collisions	Maintenance	Lading Damage	Conceptual-ization Required	Initial	Maintenance	Financial	Institutional
Improved Operations													
Mechanical and Air Coupling	1. Knuckle open	x								x	x	x	
	2. Coupler centering	x								x	x	x	
	3. Auto air line connector	x	x							x	x	x	
	4. Incompatible coupler	x								x	x	x	
Electrical Systems	5. Electrical connector	x	x						x	x	x	x	
	6. Loco-controlled coupler (including angle cock)	x	x						x	x	x	x	x
	7. Automatic bleed	x							x	x	x	x	x
	8. Loco-designated car brakes	x	x						x	x	x	x	x
	9. Ultrasonic brake control	x						x	x	x	x	x	
	10. Train condition monitor	x		x					x	x	x	x	x
Improved Dynamics													
Alternative Mechanical Systems	11. Truck-mounted brakes									x	x	x	
	12. Disk brakes									x	x	x	
	13. E coupler with shelves					x				x	x	x	
	14. High-strength couplers					x				x	x	x	
	15. Zero slack				x	x	x			x	x	x	
Electrical Systems	16. Load sensor			x	x	x	x		x	x	x	x	
	17. Radio-controlled brake link			x	x	x	x		x	x	x	x	
	18. Electropneumatic brakes			x	x	x	x		x	x	x	x	
	19. Electronic brakes			x	x	x	x		x	x	x	x	

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.

TABLE 3. STAGES OF DEVELOPMENT FROM CONCEPT TO START OF IMPLEMENTATION AND ESTIMATED TIME RANGES.

Stage	Estimated Time Range (Yr)
1. Research	1 - 2
2. Development	1.5 - 3
3. Pilot Production	0.5 - 1
4. AAR Qualification Test Program	2 - 4
5. Field Testing, Final Debugging	2.5 - 5
6. Tool up for Production	0.5 - 2
Total	8 - 17

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

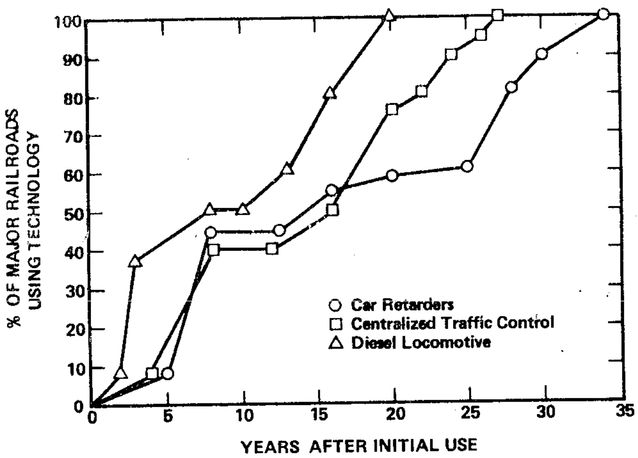


FIGURE 1. PATTERN OF ADOPTION OF NEW TECHNOLOGY [4].

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

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

*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.

*Accidents include both personal injury and damage to equipment.

TABLE 5. RAIL SYSTEM VARIABLES TO BE PROJECTED

System Variables	Related Areas
1. Number of freight cars in railroad service	Yard and transportation labor
2. Number of daily switching operations	Yard and transportation labor Accidents
3. Number of railroad yards*	Yard and transportation labor Car utilization
4. Average over-the-road train speed	Accidents Freight car maintenance
5. Average freight car capacity	Accidents Freight car maintenance

*Includes both industry and classification yards.

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

	Years		Percentage Change Over Time Period (%)
	1980	2000	
1. Number of freight cars in railroad service (thousands)	1,655	1,444	-12.7
2. Number of daily switching operations (thousands)	915	941	2.8
3. Number of classification yards	1,172	971	-17.2
4. Average over-the-road train speed (mph)	47.5	52.0	9.4
5. Average freight car capacity (tons/car)	80	100	25.0

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 reationalization 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]

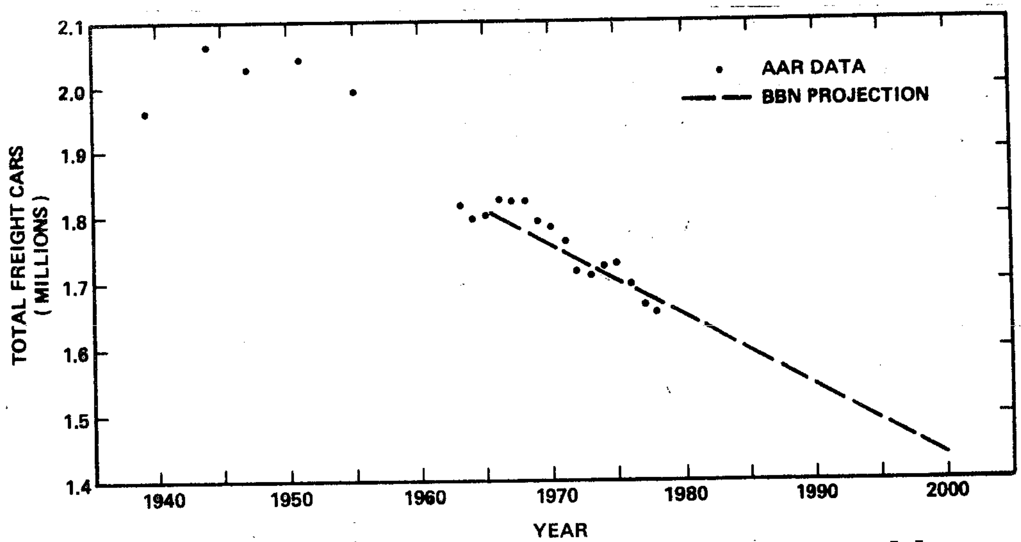


FIGURE 2. PROJECTED NUMBER OF FREIGHT CARS IN RAILROAD SERVICE [5].

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.

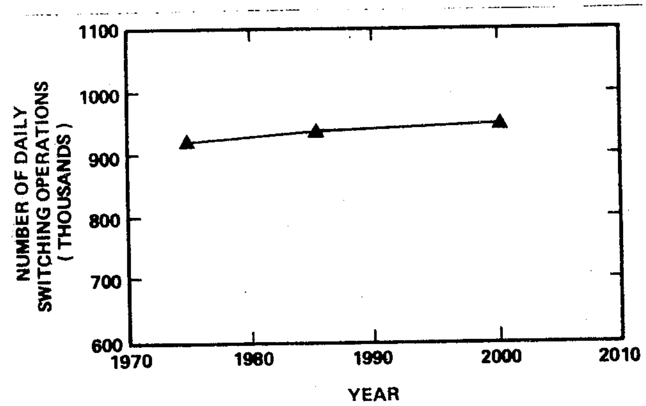


FIGURE 3. PROJECTED NUMBER OF DAILY SWITCHING OPERATIONS.

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

[Footnote cont'd.] system into the long-term future, it is felt that the present trends projection is not appropriate for our purposes. A discussion of alternative scenarios will be presented at the end of this section.

TABLE 7. RAILROAD CLASSIFICATION YARD INVENTORY AND REQUIREMENTS.

		Estimated†			Total Change
	1975-1985*	1975-1980	1980-1985	1985-2000*	1980-2000
Yards downgraded or abandoned	200	100	100	230	330
Yards expanded, reconfigures or constructed new	87	43	44	85	129
Net change during time period	-113	-57	-56	-145	-201

*Adopted from Ref. 4, p. 66.

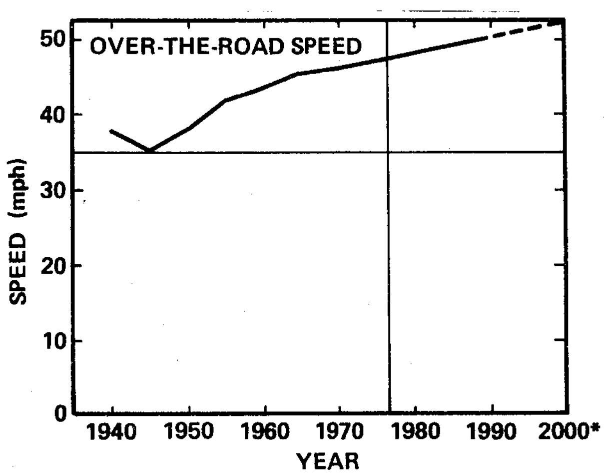
†Assumes uniform construction activity over time.

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:

1975 yard inventory [*4*]	1229
Net change 1975-1980 (Table 7)	(57)
1980 yard inventory	1172
Net change 1980-2000 (Table 7)	(201)
2000 yard inventory	971

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.



*Projections from 1990 to 2000 were estimated by BBN.

FIGURE 4. OVER-THE-ROAD FREIGHT TRAIN SPEED [*6*].

Average Freight Car Capacity

Estimates of freight car capacity are useful to estimate the parameters of future consists. Figure 5 shows historical data [*5*] 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

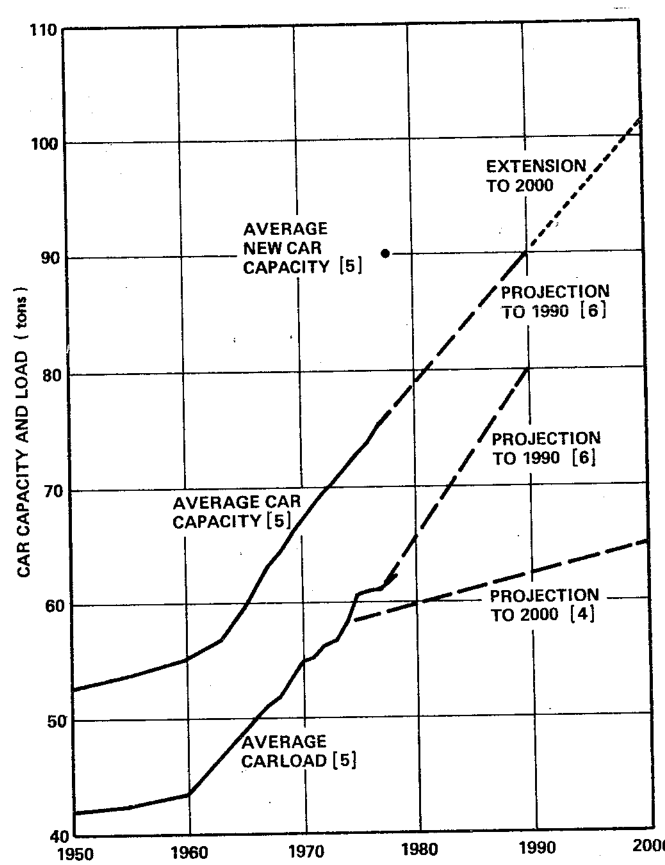


FIGURE 5. FREIGHT CAR CAPACITY AND LOAD CARRIED.

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.

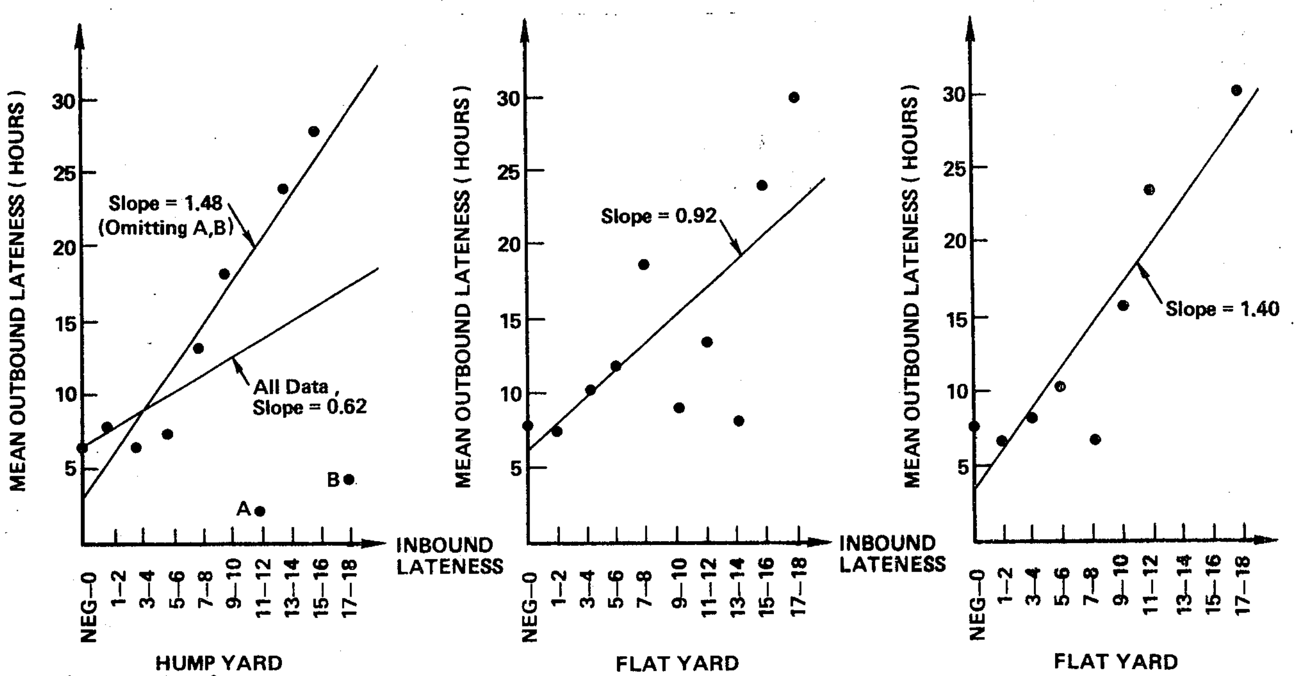


FIGURE 6. MEAN OUTBOUND LATENESS VERSUS INBOUND LATENESS [7].

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 Q_1 and time elements designated by T_1, T_2, and T_3. 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 T_i simply designate the amount of time consumed in processing a string of cars or an individual car. The average time $\overline{T}$ required to process cars from A to B simply becomes

$$\overline{T} = p_1T_1 + p_2T_2 + T_3 \, . \qquad (1)$$

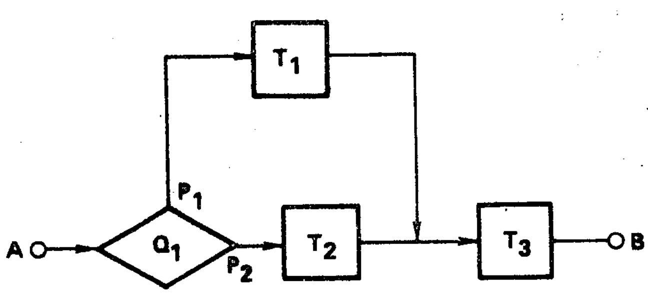


FIGURE 7. ELEMENTS OF THE METHODOLOGY.

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 p_1 and p_2 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 braker 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.

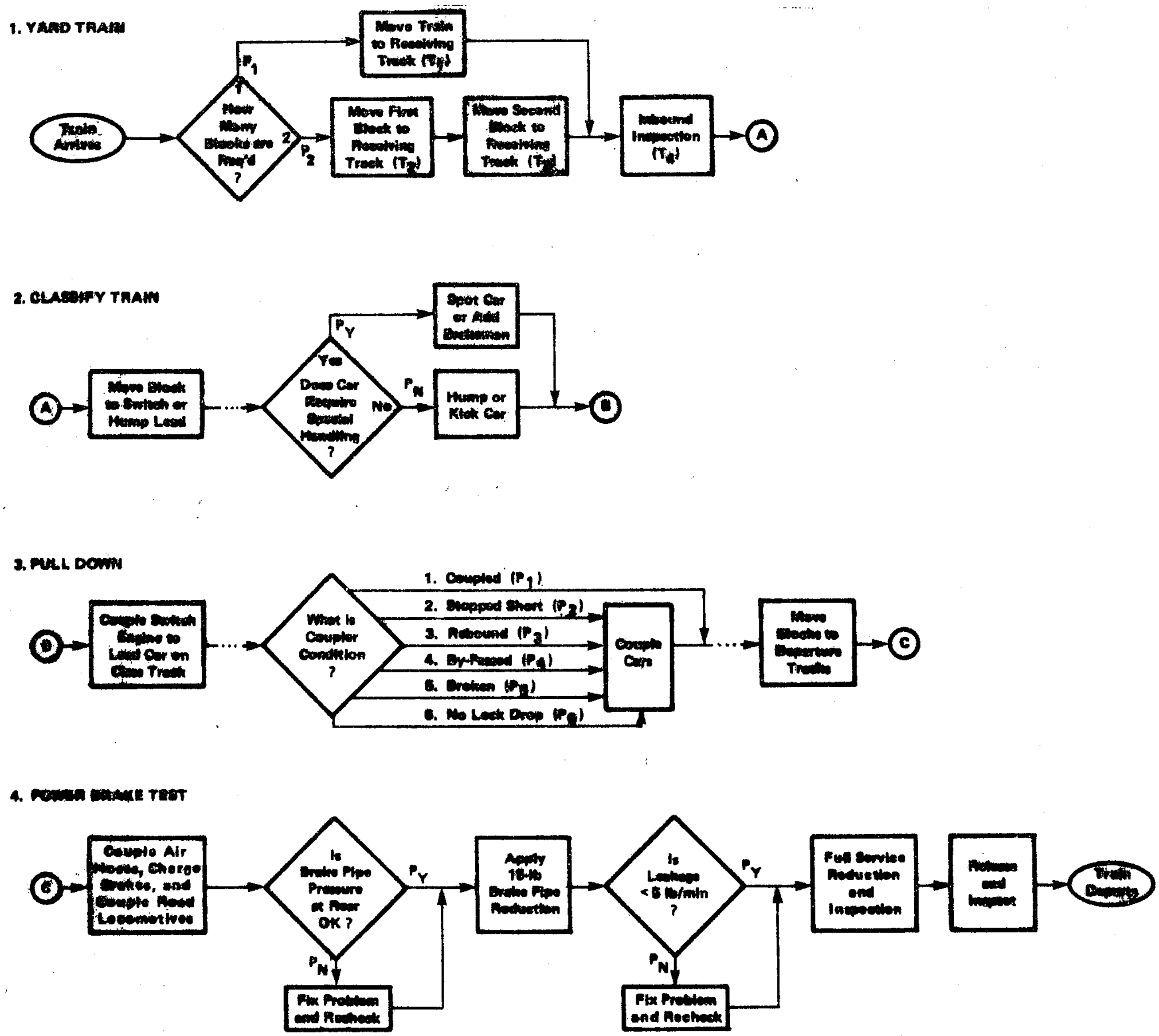


FIGURE 8. · MAJOR ELEMENTS OF YARD SIMULATION MODEL.

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

$$\int_{-(y+g_1)}^{-(y-g_2)} P(x)dx \qquad (2)$$

where g_1 = the amount one can displace the centerline of Coupler B

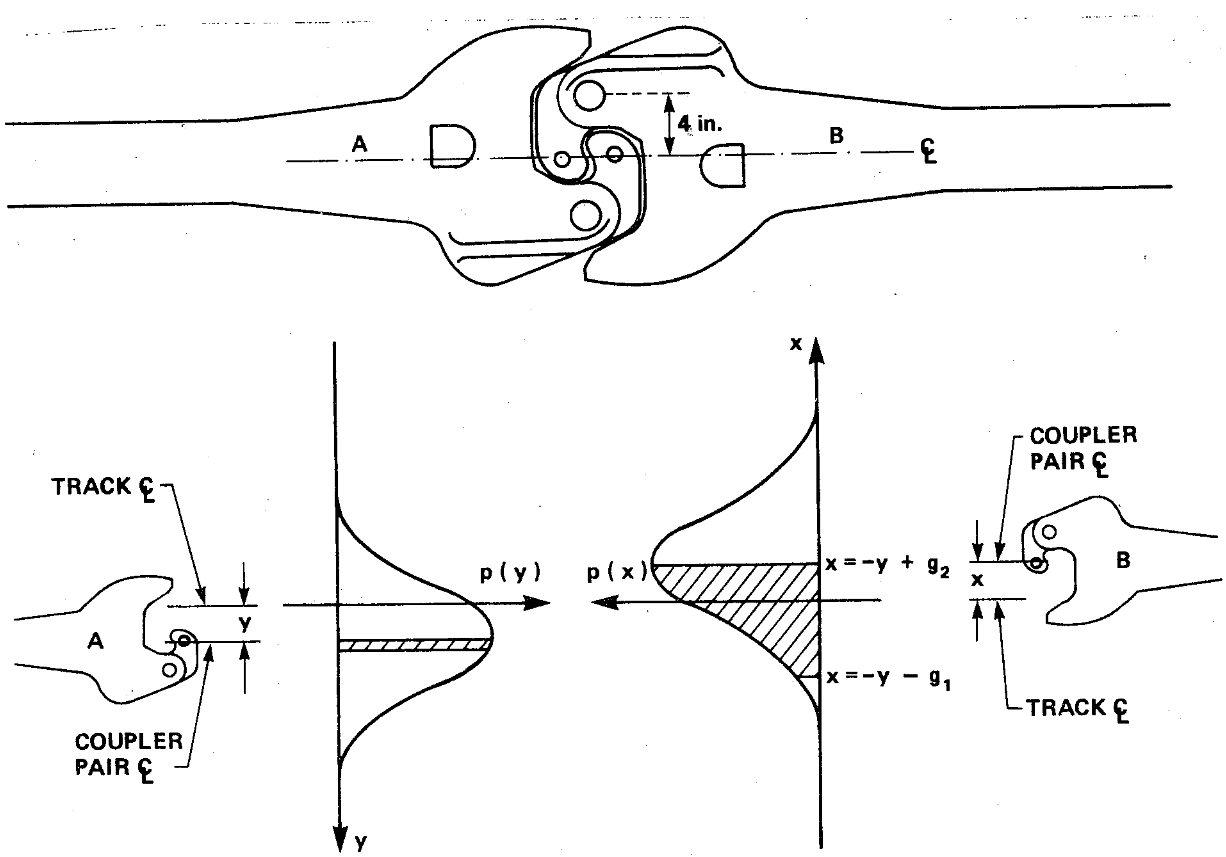


FIGURE 9. COUPLER POSITION PROBLEM.

with respect to the centerline of Coupler A, so that the knuckles move closer together and still have the couplers make;

g_2 = 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 - 1/2dy and y + 1/2dy is p(y)dy. 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:

$$P(g_1,g_2) = \int_{-\infty}^{\infty}\int_{-(y+g_1)}^{-(y-g_2)} p(y)p(x)dxdy \ . \quad (3)$$

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.

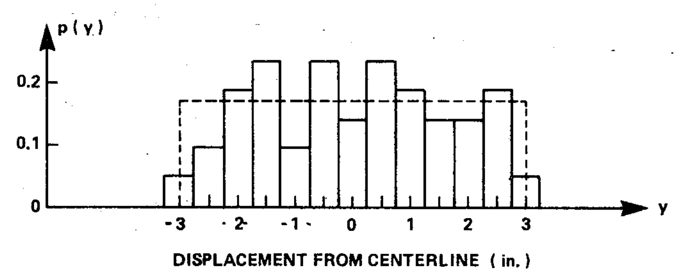


FIGURE 10. MEASURED COUPLER POSITION DENSITY FUNCTIONS.

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 very 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

$$P(g_1,g_2) = \int_{-g_1}^{g_2}\int_{-\infty}^{\infty} p(y)p(z-y)dydz \ . \quad (4)$$

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

$$p(y) = \begin{cases} 0 \ , & y < -3 \\ 1/6 \ , & -3 \le y \le +3 \\ 0 \ , & y > +3 \ . \end{cases} \quad (5)$$

Substituting this into Eq. 4, gives

$$P(g_1,g_2) = \int_{-g_1}^{g_2} f(z)dz \ , \qquad (6)$$

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

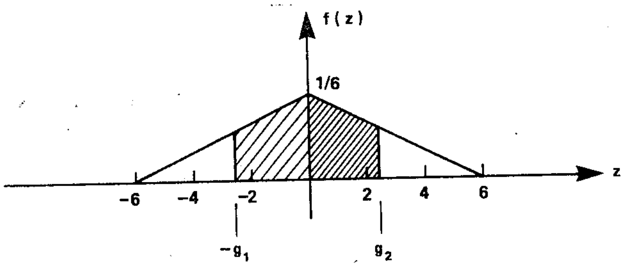


FIGURE 11. THE FUNCTION f(z).

gives the following expression

$$P(g_1,g_2) = 1 - \frac{1}{72}(g_1-6)^2 - \frac{1}{72}(g_2-6)^2 \ . \qquad (7)$$

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.

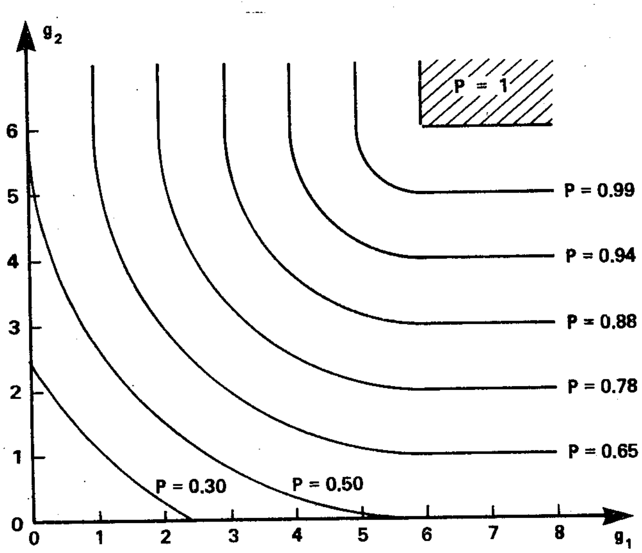


FIGURE 12. $P(g_1,g_2)$ VERSUS g_1 AND g_2.

For this example, the probability of coupling with a gathering range of 4 (i.e., ±2) in. 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., $g_1 = g_2 = 4$), 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.

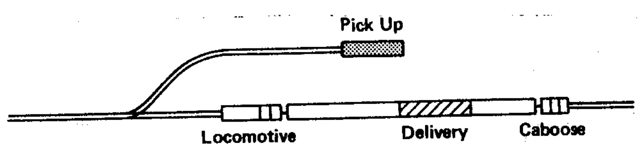


FIGURE 13. SCHEMATIC DIAGRAM OF THE MODEL.

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.

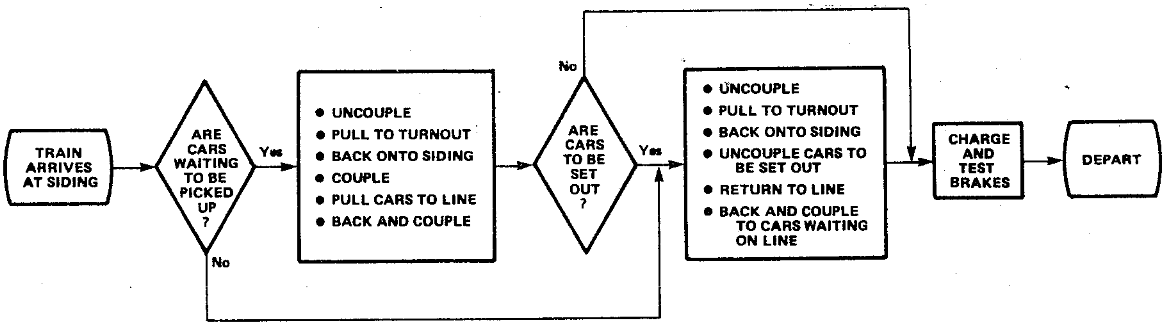


FIGURE 14. ROAD MODEL FOR LOCAL PICKUP AND DELIVERY.

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 personnel 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

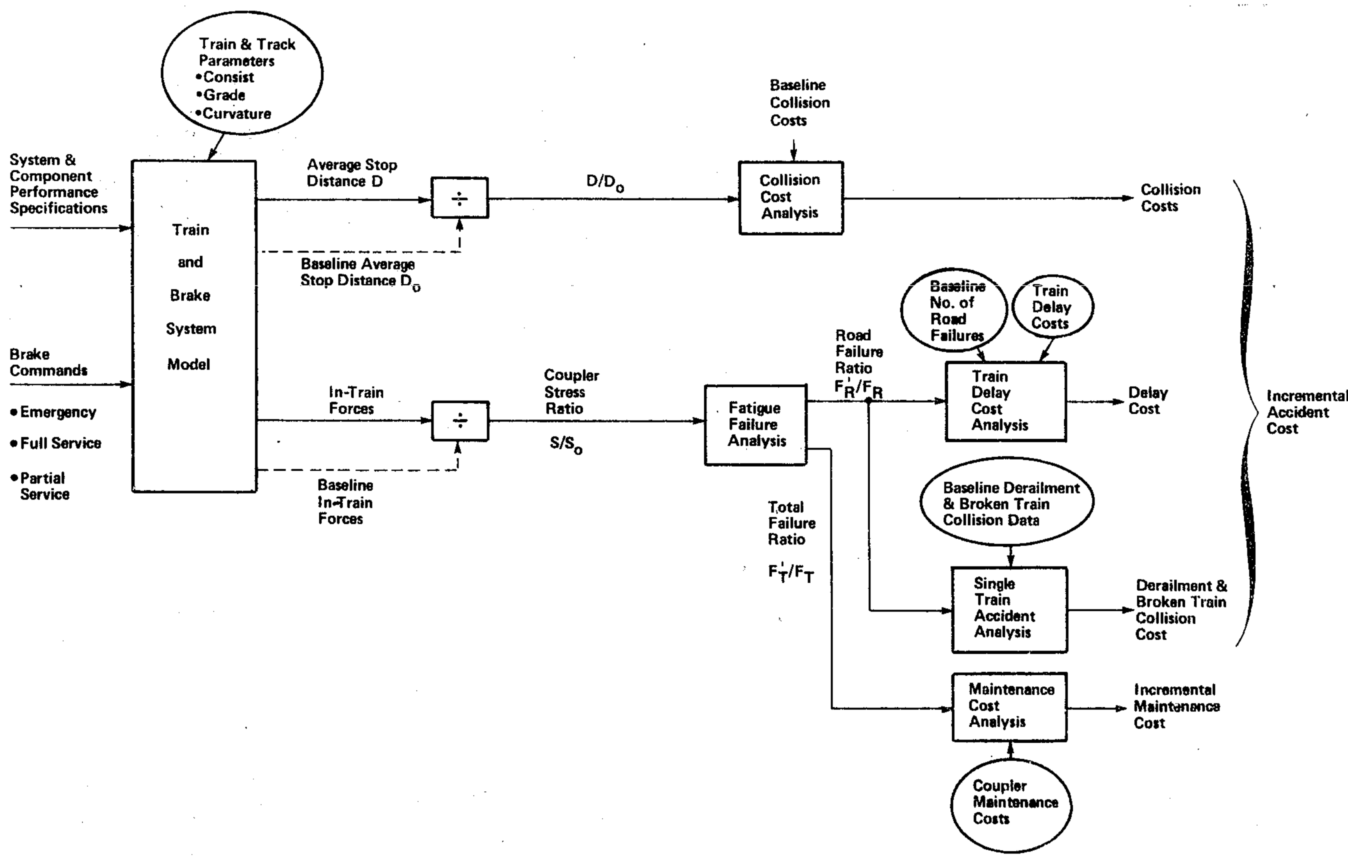


FIGURE 15. OVERVIEW OF DYNAMIC EFFECTS ANALYSIS FOR TRAINS.

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 LB5 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.

Grade	0			+1%		-1%	
% Loaded	0	50[1]	100	0	100	0	100
Speed (mph) 20							
40							
60							

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

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

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

Level of Braking	Min (6 psi)		Partial (15 psi)		Full (23 psi at 80 psi app)		Emergency	
Load Distribution	All Loaded	25E* 25L 25E 25L	All Loaded	25E 25L 25E 25L	All Loaded	25E 25L 25E 25L	Loaded	25E 25L 25E 25L
Speed (mph) 20								
40								
60								

*E indicates empty; L indicated 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

the output to avoid comparisons based on data in these areas of little confidence.

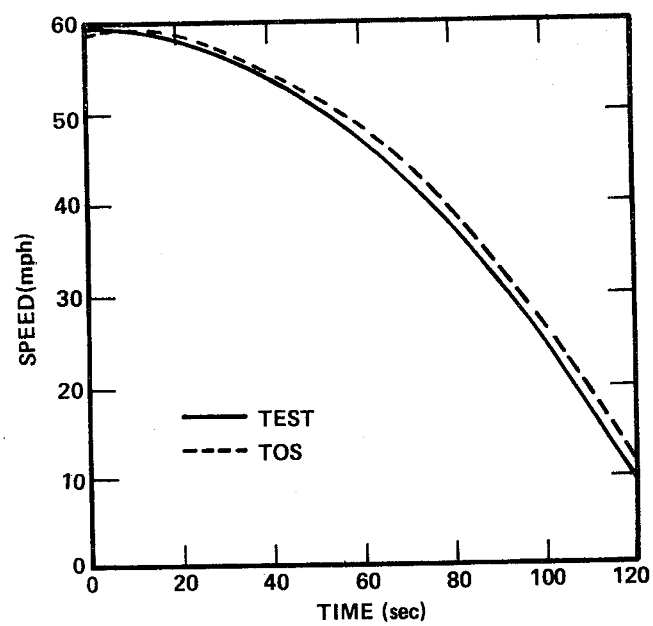


FIGURE 16. TRAIN VELOCITY VERSUS TIME FROM TOS VALIDATION REPORT [*11*].

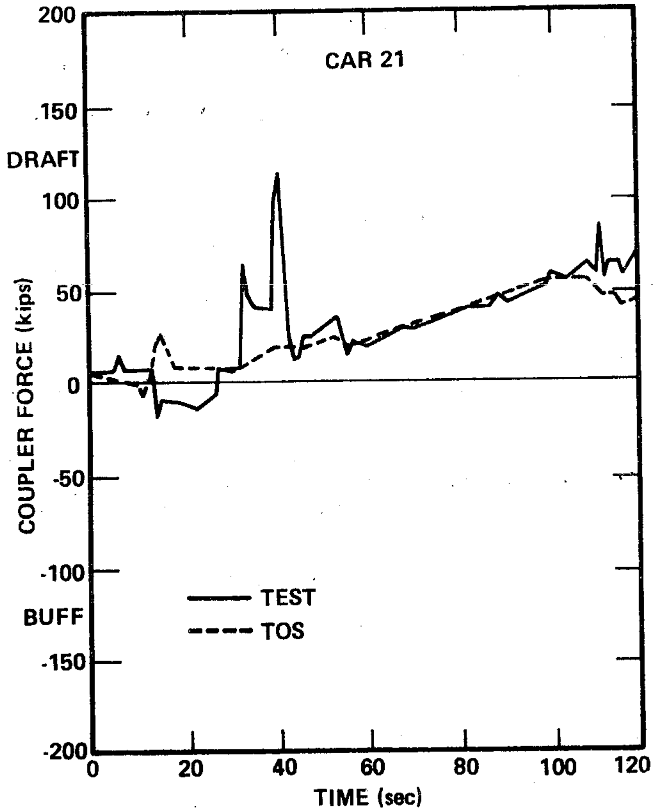


FIGURE 17. COUPLER FORCES OF CAR 21 FROM TOS VALIDATION REPORT [11].

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-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.

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

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

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
554 Train inside yard limits, excessive speed
555 Train outside yard limits under clear block, excessive speed
559 Cause code not listed; enter Code 559 in Item 35 and explain in Item 50

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 11. DIRECT ACCIDENT COSTS FOR IDENTIFIED CAUSE CODES FOR 1975 TO 1977 [12].*

Type of Accident	No.	1975 Total Cost	No.	1976 Total Cost	No.	1977 Total Cost
Head On	14	362,269	33	1,776,917	5	4,334,119
Rear End	42	3,648,127	58	987,753	52	6,365,230
Side	97	882,005	134	1,401,000	238	2,616,918
Raking	29	193,647	26	236,079	38	1,025,476
Broken Train	1	47,700	4	39,994	1	81,115
R.R. Crossing	3	429,033	2	8,726	1	659,700
Obstruction	7	215,590	4	22,760	4	85,516
Total		5,778,371		4,473,229		15,168,074

*Compiled by BBN from FRA accident tape.

TABLE 12. TRAIN ACCIDENTS BY CONTRIBUTING CAUSE SHOWING DAMAGE TRENDS, CLASS I AND CLASS II RAILROADS [*13*].

Contributing Cause and Year	Total Accidents	Percent Increase (%)	Total Damage ($)	Average Damage ($)	Damage/Mill Train Miles ($)	Accident/Mill Train Miles
HUMAN FACTORS						
1968	2,174		18,352,058	6,663	20,938	2.48
1969	2,339		23,056,564	9,857	26,683	2.71
1970	2,191		19,032,384	8,687	22,693	2.61
1971	1,912		15,732,800	8,228	20,071	2.44
1972	1,853		15,324,095	8,270	19,611	2.37
1973	2,282		27,253,258	11,943	32,782	2.74
1974	2,238		29,060,242	12,985	34,875	2.69
1975	1,847		29,971,497	16,211	39,696	2.45
1976	2,360	6.5	31,939,411	13,534	41,225	3.05
1977	2,559	106	65,679,391	25,666	87,568	3.41
EQUIPMENT FAILURES						
1968	2,042		38,891,631	19,046	44,372	2.33
1969	2,142		48,297,232	22,548	55,894	2.48
1970	1,890		38,354,491	20,293	45,732	2.25
1971	1,630		34,998,177	21,471	44,649	2.08
1972	1,577		31,188,889	19,777	39,914	2.02
1973	1,992		38,319,889	19,237	46,094	2.40
1974	2,175		49,936,473	22,595	59,929	2.61
1975	1,906		49,721,935	26,087	65,854	2.52
1976	2,174	38	68,572,507	31,542	88,508	2.81
1977	2,064	3	70,662,940	34,236	94,212	2.75
DEFECTS IN WAY OR STRUCTURES						
1968	2,128		25,288,516	13,714	28,255	2.06
1969	2,483		34,740,363	13,991	40,205	2.87
1970	2,470		38,818,645	15,716	46,286	2.95
1971	2,276		34,332,685	15,085	43,800	2.90
1972	2,544		37,908,031	14,901	48,512	3.23
1973	3,556		51,548,006	14,496	62,005	4.28
1974	4,264		70,218,582	16,468	84,270	5.12
1975	3,176		69,519,019	21,886	92,074	4.21
1976	4,260	23	85,537,356	20,079	110,404	5.50
1977	4,337	12.7	96,377,004	22,222	128,495	5.78
ALL OTHER CAUSES						
1968	1,684		24,874,058	14,771	28,379	1.92
1969	1,579		23,453,745	14,854	27,143	1.83
1970	1,544		25,419,758	16,464	30,309	1.84
1971	1,486		24,720,383	16,636	31,537	1.90
1972	1,558		23,099,325	14,826	29,561	1.99
1973	1,868		38,181,944	20,440	45,928	2.25
1974	2,017		38,485,050	19,080	46,186	2.42
1975	1,112		28,185,751	25,347	37,330	1.47
1976	1,454	45	40,941,423	28,158	52,844	1.88
1977	1,402	14	46,731,001	33,332	62,304	1.87
TOTAL ALL TRAIN ACCIDENTS						
1968	8,028		114,344,312	14,243	130,457	9.16
1969	8,543		129,547,904	15,164	149,925	9.89
1970	8,095		121,625,278	15,025	145,021	9.65
1971	7,304		109,784,045	15,031	140,059	9.32
1972	7,532		107,520,340	14,275	137,598	9.64
1973	9,698		155,303,147	16,014	186,809	11.67
1974	10,694		187,700,347	17,552	225,260	12.83
1975	8,041		177,398,202	22,062	234,954	10.65
1976	10,248	28	226,990,697	22,150	292,980	13.23
1977	10,362	23	279,450,336	26,969	372,579	13.82

*Before 1974 the train accident reporting threshold was $750; for 1975 to 1976, $1750; and for 1977, $2300.

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:

Costs:

Damage to roadway and equipment (direct cost)	$ 590,000
Freight claims paid on lading (indirect cost)	230,000
Cost of clearing wrecks (indirect cost)	201,000
	$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 [*15*]. Using the figure of 2 and extrapolating to the whole industry, the yearly accident railroad costs are approximately $30,500,000 (2 × 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.

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

TABLE 13. FATALITIES AND INJURIES FOR IDENTIFIED CAUSE CODES AND FOR ALL TRAIN ACCIDENTS [*13*].

	1975			1976			1977		
	Identified Cause Codes	% of Total	Total	Identified Cause Codes	% of Total	Total	Identified Cause Codes	% of Total	Total
Fatal	2	2.4	82	6	4	152	1	0.9	108
Injuries	106	8.7	1,720	75	59	1,279	114	11.6	985

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 14. FATALITIES AND INJURIES OF ALL ACCIDENTS IN THE RAILROAD INDUSTRY [*13*].

	1975	1976	1977
Fatalities	1,560	1,630	1,530
Injuries	54,306	65,331	67,867

*These terms are defined as follows [*13*]:

A Train Accident is a collision, derailment, fire, explosion, act of God, or other event, with or without casualties, involving railroad on-track equipment (standing or moving) which results in more than $2,300 in damages to railroad on-track equipment, signals, track, track structures, and roadbed. The damage threshold for reporting train accidents from 1957 through 1974 was $750. In 1975 the threshold was increased to

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.

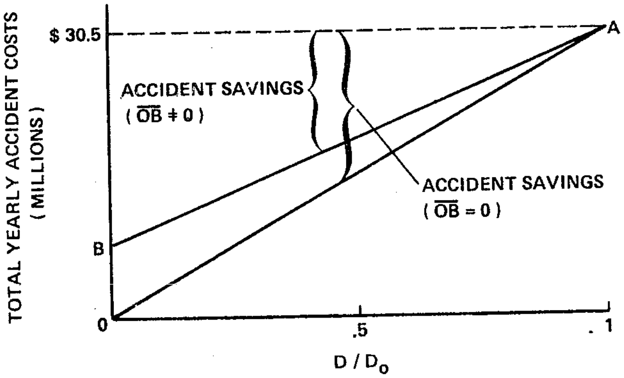


FIGURE 18. ACCIDENT COSTS VERSUS NORMALIZED STOP DISTANCE. D_0 IS THE BASELINE STOP DISTANCE. D IS THE NEW STOP DISTANCE.

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.

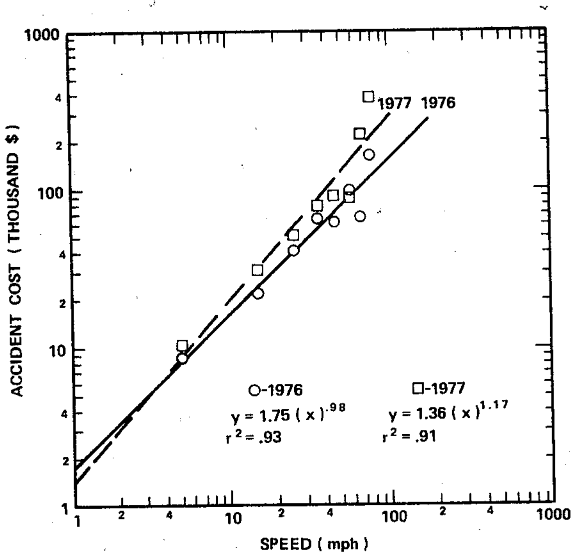


FIGURE 19. ACCIDENT COST VERSUS SPEED FOR 1976 AND 1977, SPEED COMPILED FROM TABLE 161-A OF REFS. 13 and 16.

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 costing of accident saving to the conveniently usable form:

$$\text{Savings} = (1-D/D_0)\ (\$30.5 \times 10^6)\ . \quad (8)$$

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:

$$\text{Savings} = (1-D/D_0)\ (\$30.5 \times 10^6)\ . \quad (9)$$

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" [*12*] applies to this derailment problem. Table 15 shows the casualties and costs associated with this type of accident.

TABLE 15. CASUALTIES AND COSTS FOR EMERGENCY BRAKE APPLICATION TO AVOID ACCIDENT.

	Year			3-Year Average
	1975	1976	1977	
No. of Accidents	18	17	7	14
No. of Injuries	1	2	1	1.3
No. of Fatalities	0	0		0.3
Total Dollar Value	$566,857	$719,325	$280,346	$522,176
Adjusted Dollar Value* (M $)	1.1	1.4	0.6	1.0

*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 couple. The mechanical failure of couplers and draft gear contributes to train delays, maintenance costs, and occasional derailments and collisions.

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)

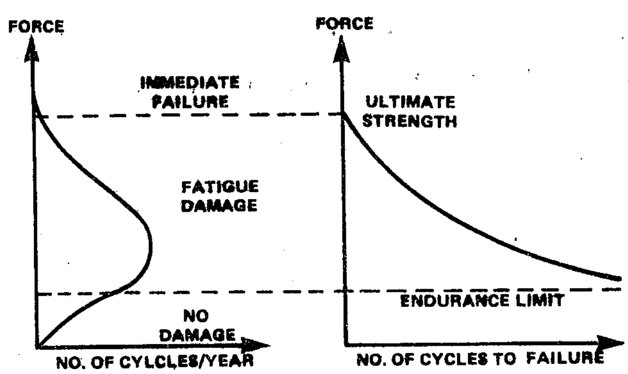


FIGURE 20. HYPOTHETICAL LOAD DISTRIBUTION AND FATIGUE CURVES FOR COUPLERS ILLUSTATING POTENTIAL FAILURE AND FATIGUE DAMAGE REGIMES.

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-RPI 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 × 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 × 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 × 2/5053 = 679.6 where the first number is the 1972 population of freight cars [*5*] 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.

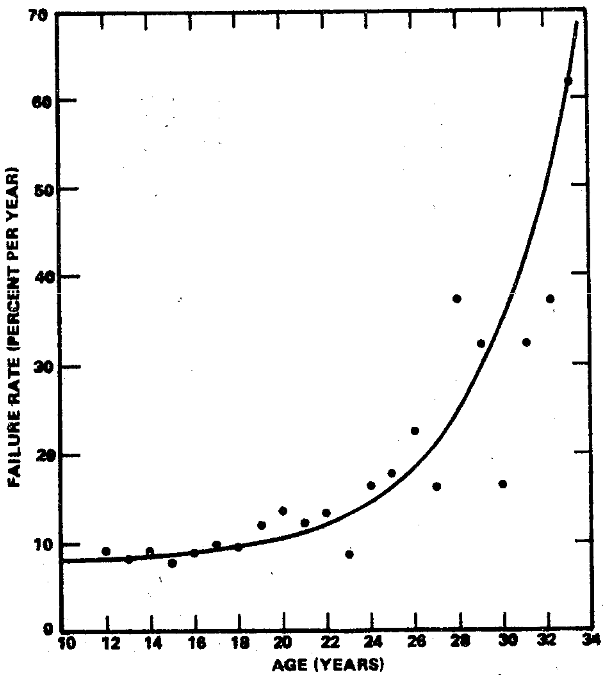


FIGURE 21. FAILURE RATE FOR E60 COUPLERS AS A FUNCTION OF COUPLER AGE.

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

$$\frac{n_Y}{N_Y} + \frac{n_R}{N_R} = 1 \quad . \qquad (10)$$

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,

$$\frac{n_Y'}{N_Y} + \frac{n_R'}{N_R'} = 1 \quad , \qquad (11)$$

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,

$$\frac{n_Y}{n_R} = \frac{n_Y'}{n_R'} \quad . \qquad (12)$$

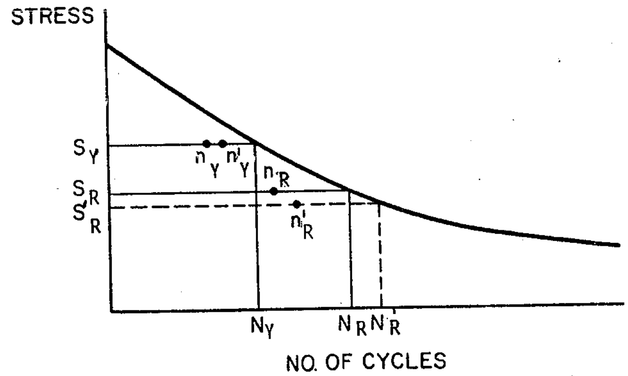


FIGURE 22. GENERAL S-N CURVE.

The portion of the fatigue curve shown in Fig. 22 above the endurance limit is described by $S^{\alpha}N = B$, where α and B are empirically determined constants. Thus,

$$S_Y^{\alpha}N_Y = B \qquad (13)$$

$$S_R^{\alpha}N_R = B \qquad (14)$$

$$S_R'^{\alpha}N_R' = B \quad . \qquad (15)$$

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

$$\frac{F_T'}{F_T} = \frac{n_R}{n_R'} = \frac{n_Y}{n_Y'} \quad . \qquad (16)$$

From Eqs. 10–16 one obtains

$$\frac{F_T'}{F_T} = \frac{n_Y}{N_Y} + \frac{n_R}{N_R}\left(\frac{S_R'}{S_R}\right)^{\alpha} \quad . \qquad (17)$$

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 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,

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

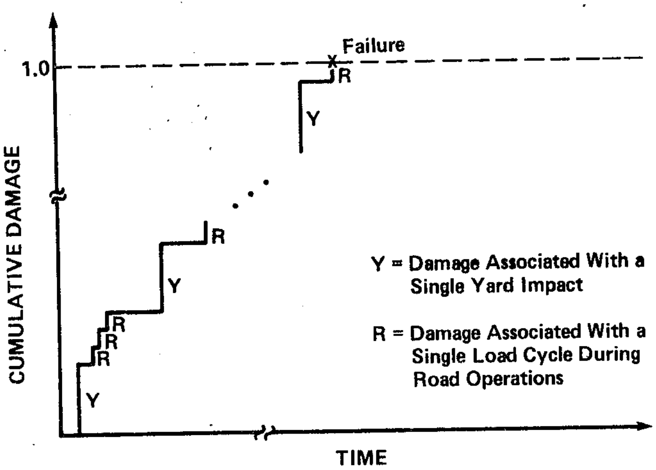


FIGURE 23. CUMULATIVE DAMAGE PLOT.

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

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

Thus,

$$\frac{F_T'}{F_T} = P_Y + P_R \left(\frac{S_R'}{S_R}\right)^{\alpha} \quad . \qquad (20)$$

The probabilities P_Y and P_R can be evaluated experimentally from data on yard and road failures which are available from the RPI-AAR Coupler Safety Research and Test Project. During a 14-week summer and winter survey period 1663 broken knuckles, couplers, and yokes were reported by participating railroads [Ref. 18, Table 8].* During the same time 314 train break-in-twos occurred [Ref. 18, Table 11]. Accordingly,

$$P_Y = \frac{1349}{1663} \approx 0.8$$

$$P_R = \frac{314}{1663} \approx 0.2 \ .$$

*In addition, several thousand cracked knuckles, couplers, and yokes were detected and changed out before a complete break occurred.

The value of the exponent α 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 α for these data range from 5.1 to 8.5.

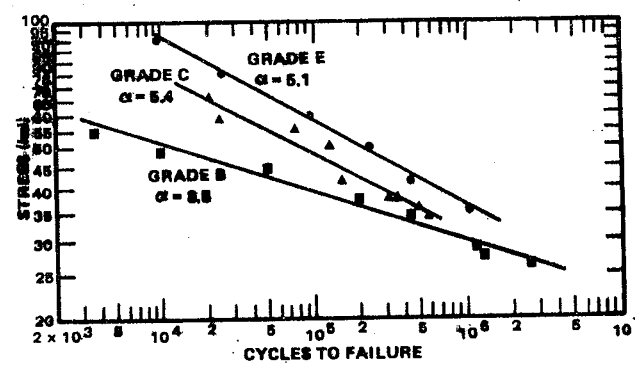


FIGURE 24. FATIGUE FAILURE CURVES FOR THREE GRADES OF COUPLER STEEL [20].

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

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

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

$$\frac{F_R'}{F_R} = \frac{F_T' P_R'}{F_T P_R} \quad . \qquad (22)$$

Since $F_T'/F_T = n_R/n_R'$, Eqs. 18 and 22 become

$$\frac{F_R'}{F_R} = \frac{N_R}{N_R'} = \left(\frac{S_R'}{S_R}\right)^{\alpha} \quad . \qquad (23)$$

Equations 20 and 23 are plotted in Figure 25 to illustrate the dependence of failure rate on stress level. Both curves are for α = 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 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.

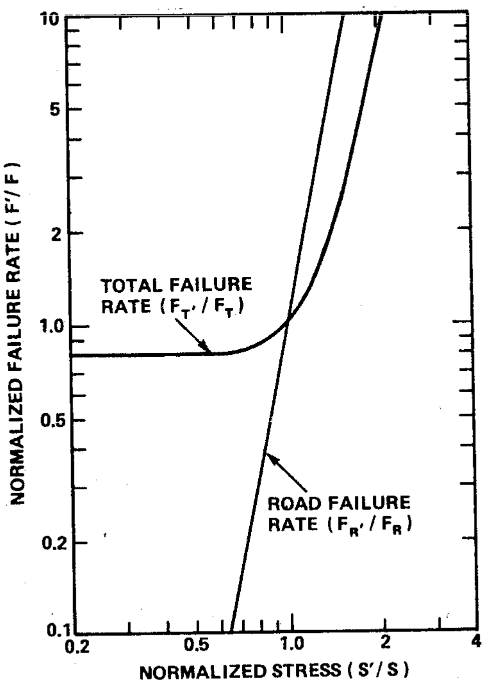


FIGURE 25. FAILURE RATE VERSUS STRESS RATIOS FOR α = 5.1.

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.

Number and Duration of Train Delays

Three studies have been conducted that can be used to estimate delays associated with coupler failure. We will extract the relevant information from each and compare the results.

RPI-AAR Coupler Project. During a 10-week summer period in 1971 and a 4-week winter period early in 1972, a team sponsored by the Railway Progress Institute (RPI) and the AAR collected broken couplers, knuckles, and yokes on five major railroads* [*17,18*]. 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 16. TRAIN DELAY DATA FOR FAILED COUPLER, KNUCKLES, AND YOKES [*18*].

	No. of Failures		
Train Delay (min)	Summer Period	Winter Period	Total
0 - 15	155	1567	1722
> 15	78	170	248
Unknown	2217	96	2313

A dissaggregation 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 17. DELAYS CAUSED BY COUPLER, KNUCKLE, AND YOKE FAILURES [*18*].

	Summer Period (10 Wks)		Winter Period (4 Wks)		Total (14 Wks)	
	No*	Average Delay (min)	No*	Average Delay (min)	No*	Average Delay (min)
Couplers	23	66.4	95	83.4	118	80.1
Knuckles	44	51.5	55	62.1	99	57.4
Yokes	11	58.5	20	89.9	31	78.8
Total	78	56.9	170	77.3	248	70.9

*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

*Atchison, Topeka & Santa Fe; Burlington Northern; Norfolk and Western; Southern; and Union Pacific.

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 6 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 18. ESTIMATE OF THE SAMPLE SIZE OF THE RPI/AAR COUPLER FAILURE STATISTICS AS A PERCENTAGE OF THE NATIONAL TOTAL.

	Source	Period	No. of Reported Coupler Body Failures	Estimated Total Failures for Quarter	Percent Estimated Sample of Total (%)
Summer Period	AAR-CRB Data	7/01/72 - 9/30/72 (13 wks)	6817	(x6) 40902	2.52
	RPI/AAR Coupler Project	6/01/71 - 8/07/71 (10 wks)	793	(x1.3) 1031	
Winter Period	AAR-CRB Data	1/01/72 - 3/31/72 (13 wks)	6895	(x6) 41370	5.66
	RPI/AAR Coupler Project	1/15/72 - 2/14/72 (4 wks)	721	(x3.25) 2343	

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 19. PROJECTION OF DELAY TIMES TO A NATIONAL AVERAGE.

Period	Component	(1) No. of Reported Delays	(2) Estimated No. Per Quarter*	(3) Estimated National Total†	(4) Average Train Delay (min)	(5) Total Train Delay Per Quarter (hr)
Summer	Coupler	23	29.9	1186.5	66.4	1,313.1
	Knuckle	44	57.2	2269.8	51.5	1,948.3
	Yoke	11	14.3	567.5	58.5	553.3
						3,814.7
Winter	Coupler	95	308.8	5454.9	83.4	7,582.4
	Knuckle	55	178.8	3158.1	62.1	3,268.7
	Yoke	20	65.0	1148.4	89.9	1,720.7
						12,571.8

*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 7½-MONTH PERIOD ON THE SOUTHERN RAILWAY [*15*].

Component	No.	Average Delay Per Failure (hr)
Knuckle	270	1.2
Coupler	213	2.05
Yoke	10	3.0
Key	10	2.7
Carrier	8	2.5
Follower Stops	1	1.5
End Sill	7	2.25
Center Sill	5	3.0
Total	524	1.66

$$D_T = (524)(1.66)\ \frac{12}{7.5}\ \frac{TM_n}{TM_s}\ , \qquad (24)$$

where the ratio 12/7.5 scales the data to a full year, $TM_n = 858 \times 10^9$ is the national revenue ton miles for 1978 [*5*], and $TM_s = 44 \times 10^9$ 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 [*23*]. 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

$$D_T = 34 \times \frac{76}{60} \times \frac{432{,}944}{152} = 122{,}667 \text{ train hr,} \qquad (25)$$

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:

*It was not possible to determine from the report the delay for mechanical failures only.

Source	Estimated Total Delay (Train Hr)
RPI/AAR Coupler Project [*18*]	32,773
Southern Railway [*15*]	27,139
MIT Study of Penn Central [*23*]	122,667

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 inconsistences 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). Firms A and B

†Railroads that provided information for this study requested that their names not be divulged.

TABLE 21. COSTING METHODOLOGIES FOR TRAIN DELAY TIME.

	Included in Costing Methodology			
	A	B	C	D
Cost Elements				
Time Cost of Equipment				
Locomotives	yes	yes	yes	yes
Freight Cars	yes	yes	yes	yes
Freight Cars Per Diems	no	no	yes	no
Fuel Expense	yes	yes	yes	yes
Cost of Crew Time	yes	no	yes	yes
Maintenance Costs	no	yes	no	yes
Costing Variables				
Valuation Methodology for Cost of Equipment	DCF*	DCF	DCF	DCF
Internal Rate of Return (%)	20	20	N/A	20
Hours in Train Year	8760	5840	8760	8760

*Discounted Cash Flow.

cost only owned equipment, whereas Firm C considers both owned equipment and foreign cars.*

- Fuel expense is included by all firms.

- Cost of crew time is included by Firms A and C, but Firm B excludes this cost because its crews are paid on the basis of miles rather than hours.†

- Maintenance costs are included by Firm B. Firms A and C disregard these costs on the basis that the main determinant of maintenance expense is mileage-operated, and therefore maintenance expense does not accrue if equipment is idle.**

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 [*24*].
- 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**
	$29,452
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 [*5*]. Taking 35.4% of these values and dividing by 141,220 train and engine service employees gives the above results.**

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

†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.

††AAR weighted national average price for diesel fuel as of August 1979. (Personal communication with J. Dale of the AAR in August 1979.)

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:		
3 locomotives × $15.89/loco/hr	**=**	**$ 47.67**
Freight Cars:		
68 cars × 0.78/car/hr	**=**	**53.04**
Fuel:		
3 locomotives × $3.30/loco/hr	**=**	**9.90**
Crew:		
4 men × $14.16/hr	**=**	**56.64**
Maintenance:		
3 × $4.83/loco/hr	**=**	**14.49**
68 × 1/2 $0.12/car/hr	**=**	**4.08**
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 22. SUMMARY OF TRAIN DELAY COSTS.*

Time Cost of Equipment	8,760-Hr Yr	5,840-Hr Yr
Locomotives	$47.67/hr	$71.51/hr
Freight car (ownership cost)	53.04/hr	79.56/hr
Freight car (ownership cost and *per diem*)	43.18/hr	64.77/hr
Fuel Expenses	9.90/hr	9.90/hr
Cost of Crew Time	56.64/hr	56.64/hr
Maintenance Costs	18.57/hr	27.86/hr
Total	$175.96 - $185.82/hr	$230.68 - $245.47/hr

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

*We have not included incentive *per diems* 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 goves

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.

TABLE 23. DERAILMENTS AND BROKEN TRAIN COLLISIONS CAUSED BY COUPLER FAILURES [12].

Cause Code*	Derailments 1975 No.	Derailments 1975 Cost†	Derailments 1976 No.	Derailments 1976 Cost	Derailments 1977 No.	Derailments 1977 Cost	Broken Train Collisions 1975 No.	Broken Train Collisions 1975 Cost	Broken Train Collisions 1976 No.	Broken Train Collisions 1976 Cost	Broken Train Collisions 1977 No.	Broken Train Collisions 1977 Cost
430 Knuckle Broken or Defective	39	552	35	652	30	680	4	30	4	28	3	30
432 Coupler Drawhead Broken or Defective	126	3332	128	3489	94	2114	9	243	5	61	2	26
434 Draft Gear/Mechanisms Broken or Defective (including yoke)	26	413	46	1036	36	1137	1	2	1	3	2	45
435 Coupler Carrier Broken or Defective	20	207	17	659	21	661	5	43	1	4	0	0
436 Coupler Shank Broken or Defective	0	0	0	0	13	486	0	0	0	0	0	0
Total Identified Causes:	211	4504	226	5836	194	5078	19	318	11	96	7	101
439 Cause Code Not Listed	20	492	35	276	38	906	9	304	6	199	3	58
Total All Causes	231	4996	261	6113	232	5984	28	622	17	295	10	159

*Including locomotives

†Costs in thousands of dollars.

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 [25] 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 24. ESTIMATED ANNUAL COUPLER REPLACEMENT COSTS.

	Estimated Cost Per Component* ($) Labor	Material	Scrap Credit	Total	Industry Impact: Broken No. (Thous)	Broken Percent (%)	Broken Cost (Mil of $)	Worn No. (Thous)	Worn Percent (%)	Worn Cost (Mil of $)	Total No. (Thous)	Total Cost (Mil of $)
Couplers	26.43	217.37	(9.42)	234.38	136.2	60	31.92	90.8	40	21.28	227	53.20
Knuckles	3.51	47.48	(2.37)	48.62	373.5	75	18.16	124.5	25	6.05	498	24.21
Yokes	57.88	127.87	(4.38)	181.37	69.6	94	12.62	4.4	6	0.80	74	13.42
					579.3		62.70	219.7		28.13	799	90.83

*Labor and material costs are taken from Ref. 25. Coupler material costs apply to an E60CHTE coupler body (Job Code 2022), knuckle costs to a E50HT knuckle (Job Code 2052), and yoke costs to a Y40AHT yoke (Job Code 2314).

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 25. SUMMARY OF POTENTIAL SAVINGS ASSOCIATED WITH THE ELIMINATION OF COUPLER, KNUCKLE, AND YOKE FAILURE.

Location	Cause	Annual Cost (Millions of Dollars)
Road	Train delays	6.0
	Derailments & collisions	12.0
	Coupler, knuckle, & yoke repair & replacement	12.5
	Total Road	30.5
Yard	Coupler, knuckle, & yoke repair & replacement	50.2
	Total	80.7

4.7 Lading Damage

Lading mabe 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 sil 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 identifed 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, gain, 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 26. COMMODITY DAMAGES WHICH ARE POTENTIALLY AVOIDABLE THROUGH CAR IMPACT CONTROL [28].

AAR Code	Commodities	Payment in 1977 (dollars)
012	All Fresh Fruits and Tree Nuts	881,796
013	All Fresh Vegetables	1,054,708
2031	Canned or Cured Sea Foods	338,499
2032	Canned Specialties	112,717
2033	Canned Fruits or Vegetables	1,657,110
2035	Pickled Fruits or Vegetables	169,617
2039	Mixed Shipments of Canned Goods	988,242
20821	Beer	1,803,907
2084	Wines, Brandy	340,269
20851	Whiskey	440,612
209	Misc. Food Preparations	7,326,757
2432	Plywood or Veneer	1,098,101
25	Furniture and Fixtures	2,293,335
26211	Newsprint	3,339,302
321	Flat Glass	742,019
322	Glassware	194,987
34	Fabricated Metal Products	2,075,750
35	Machinery Except Electrical	3,310,877
363	Household Appliances	1,957,621
3711	Motor Vehicles	66,127,720
3714	Motor Vehicle Parts	2,864,763
	Total	99,118,709

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 costings 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:

- FRA switching regulations for cars containing hazardous materials
- FRA 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:* FRA 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.

• *FRA Power Brake Regulations:* Certain changes in FRA 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 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 apparently limits 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.

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*Institutional policy areas, such as railroad deregulation, that can *indirectly* affect benefits from advanced braking and coupling technology are not included in this analysis.

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 varous 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:

$$NPV = \sum_{t=0}^{\infty} \frac{C_t}{(1+P)^t} , \qquad (27)$$

where 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.

$$\sum_{t=0}^{\infty} \frac{C_t}{(1+IRR)^t} = 0 . \qquad (28)$$

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:

Year	0	1	2	3	4	5-25	26→∞
Cash Flow	-1000	-1000	+300	+300	+400	+500	0

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.

Benefits*	Adjustments to Benefits	Structural Parameters
• Labor savings per year subject to union payout • Savings per year not subject to union payout	• Material/labor inflation rates • Fraction of labor savings paid to union • Number of years of union payout • Depreciation method • Fraction of investment allowable for investment tax credit • Federal tax rate	• Number of cars in system • Years to system compatibility • Years cash flows to be calculated • Asset lifetime • Fraction of cars replaced per year • Fraction of retrofit cost required per new car production • Internal rate of return

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

TABLE 28. SYSTEM BENEFITS.

Potential Savings/Costs Changes	Data Source
• Yard and over-the-road labor	Operations analysis
• Car utilization	Operations analysis
• Equipment and lading damage	Dynamic analysis
• Maintenance costs	Dynamic analysis and equipment ana-ysis
• Equipment wear	Dynamic analysis

- *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.

†These rates have a history of changing over time. At present, 10% is the allowable rate.

- *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 compatability* 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.

- *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. Where 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.

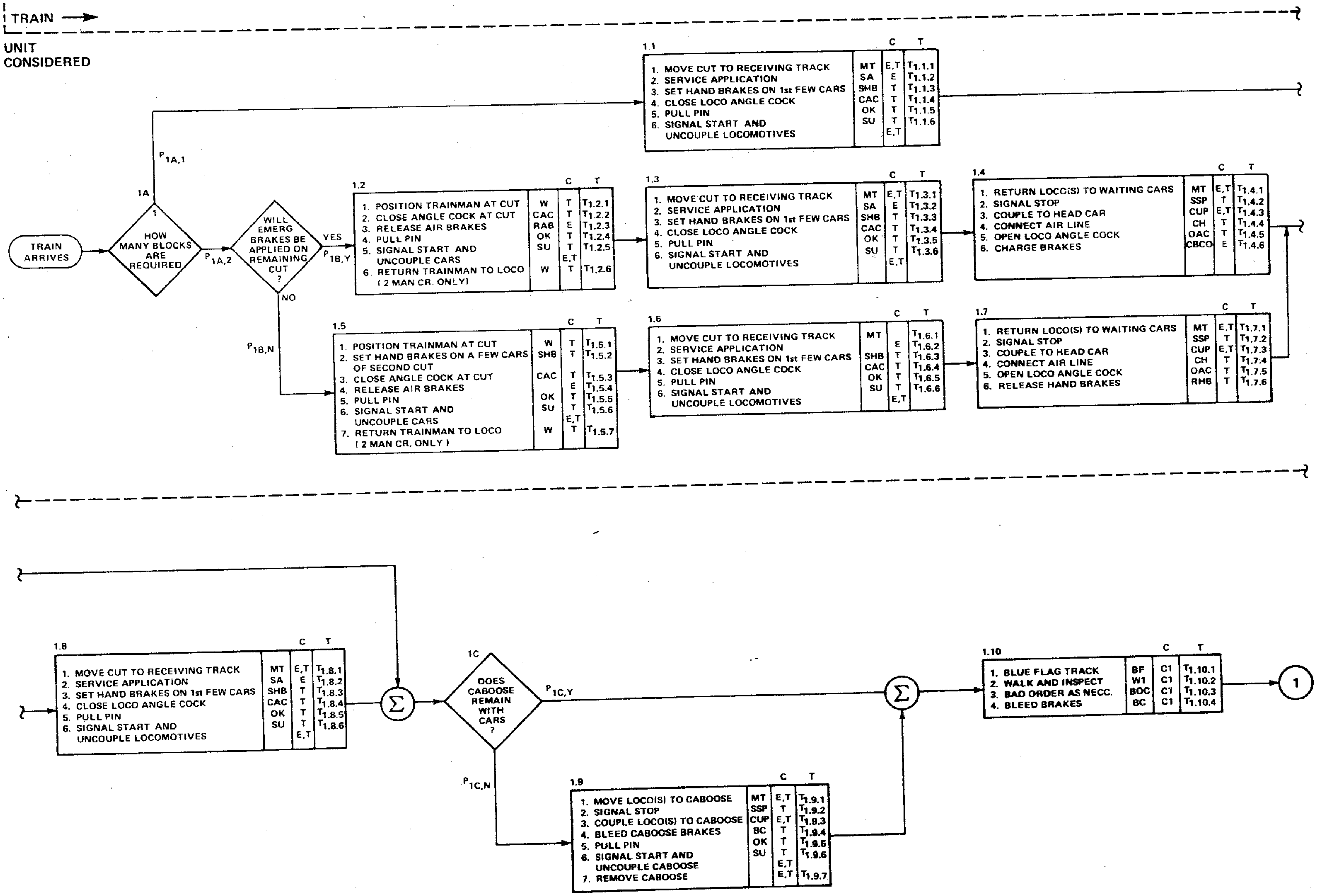
The model presented here should be viewed as a model for a hypothetical yard. It contains all the major tasks that are performed on cars as they pass through a yard; however, there are yards which may not fit the model because they perform the tasks in a different order.

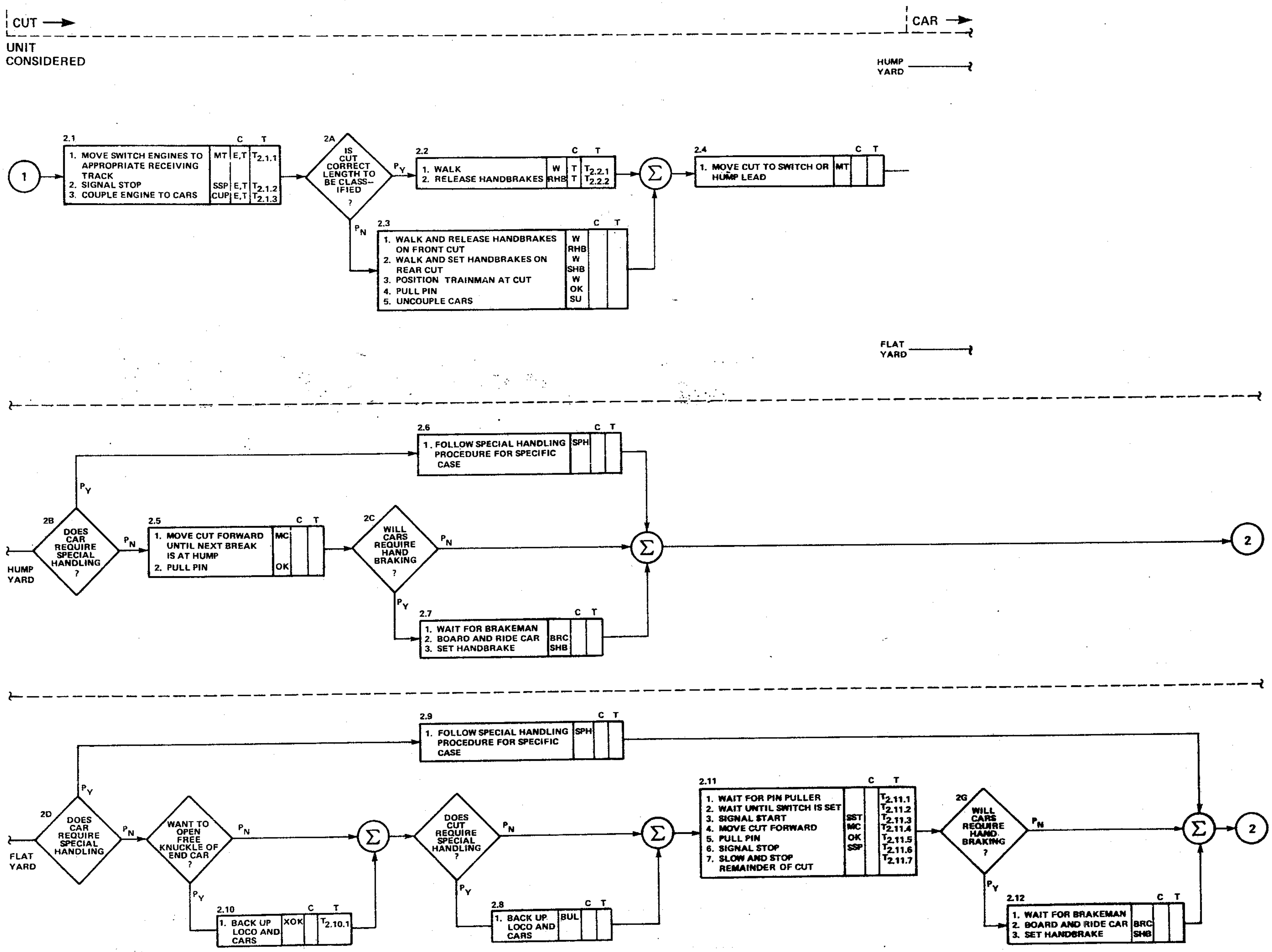
There is one flow chart for each of the major yard operations: (1) inbound inspection and bleeding the cars, (2) classification (hump yard or flat yard), (3) pull down, and (4) connecting the air, charging the train, and the power brake test. Each chart allows several probability splits, depending, for 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.

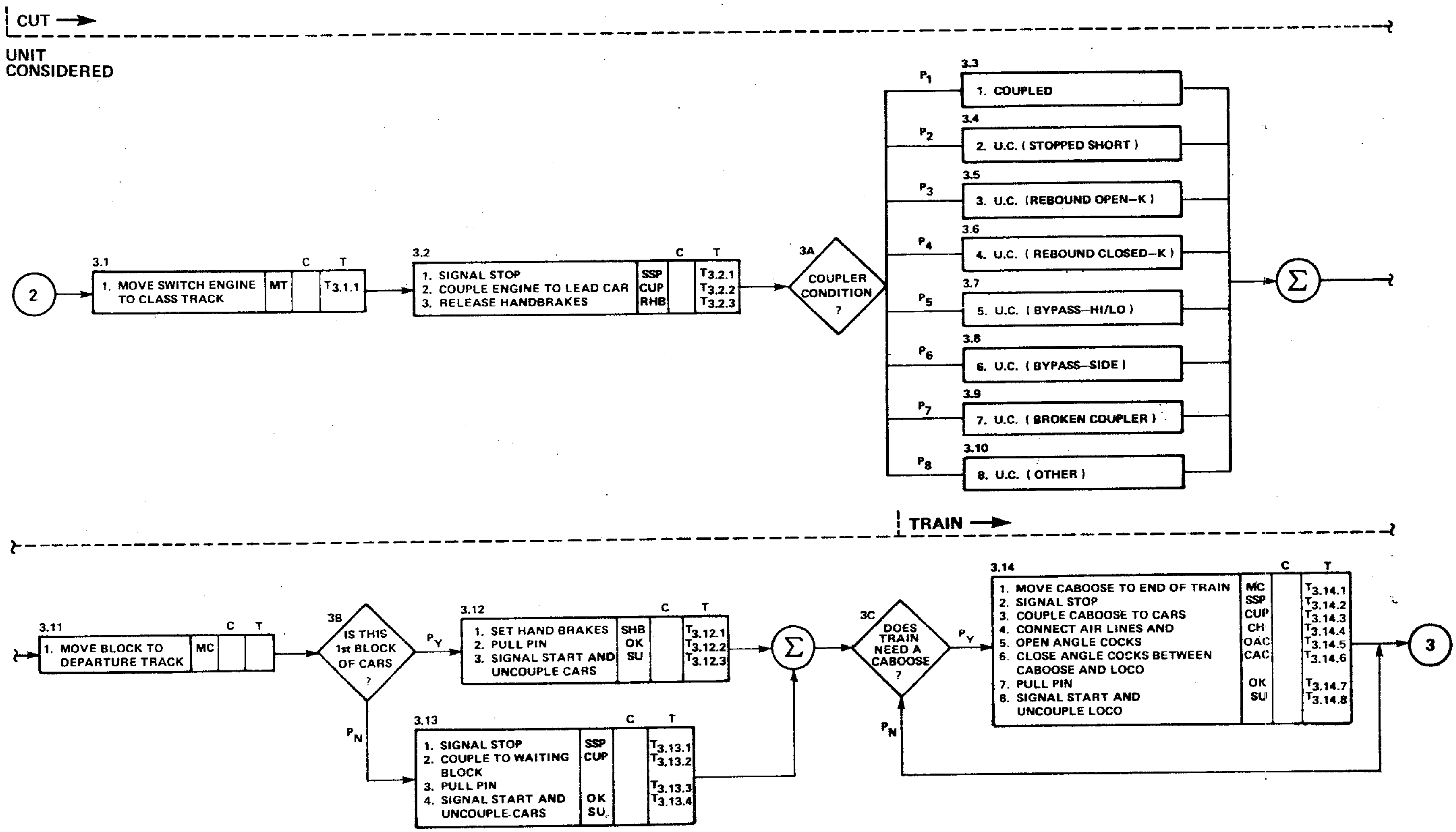
The computer adds up the time for all tasks and multiplies by the number of cars classified per year. It then multiplies by labor rate of the crews performing the tasks or the rate for car time or locomotive time. The program is designed to calculate the difference between a baseline case and a change 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:

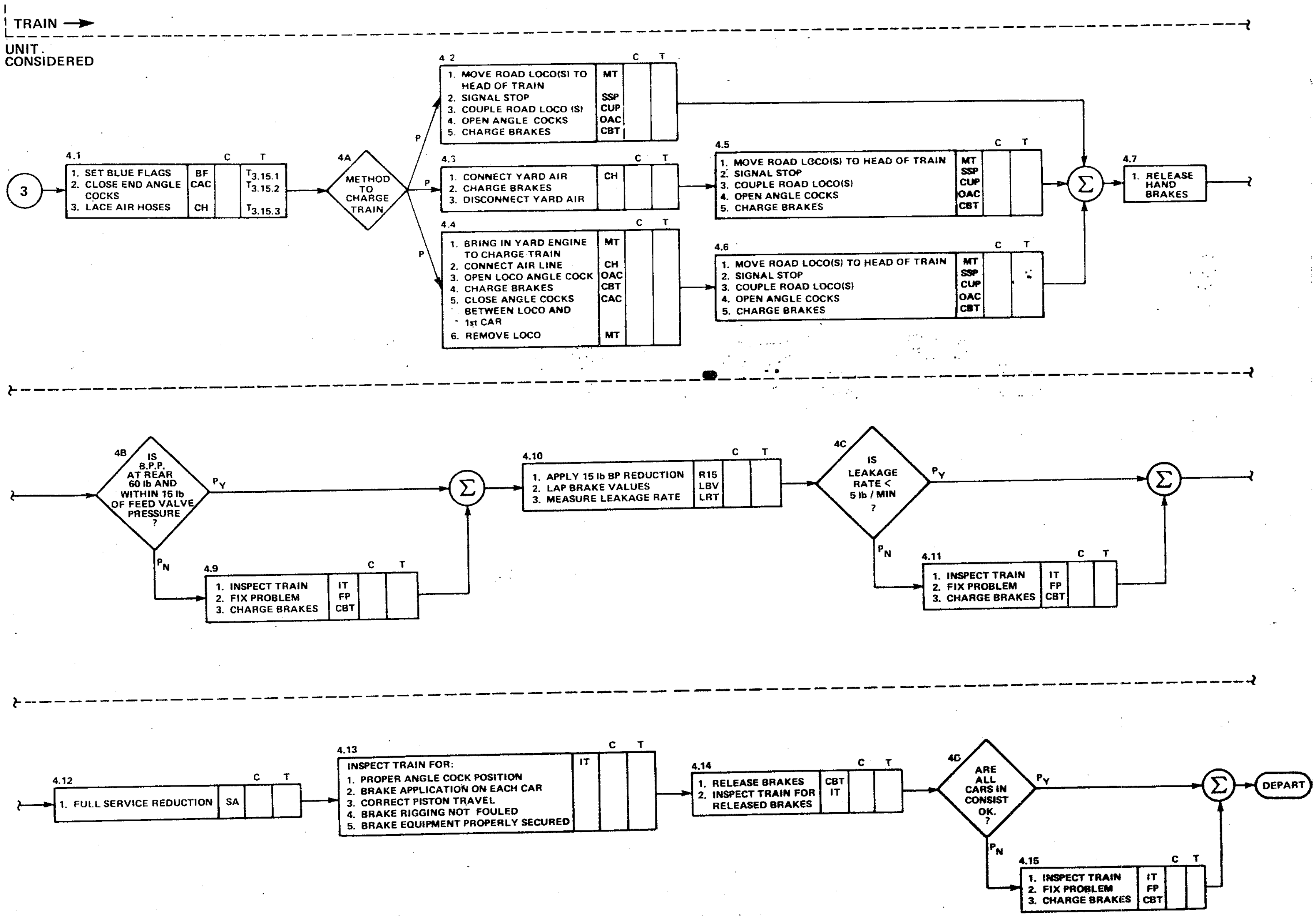
- Road crew
- Yard crew
- Car inspectors
- Road locomotives
- Switch engines
- Car utilization.

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.


TRAIN
UNIT CONSIDERED
TRAIN ARRIVES
1A
1
HOW MANY BLOCKS ARE REQUIRED
P1A,1
P1A,2
WILL EMERG BRAKES BE APPLIED ON REMAINING CUT ?
YES
NO
P1B,Y
P1B,N
1.1
C
T
1. MOVE CUT TO RECEIVING TRACK MT E,T T1.1.1
2. SERVICE APPLICATION SA E T1.1.2
3. SET HAND BRAKES ON 1st FEW CARS SHB T T1.1.3
4. CLOSE LOCO ANGLE COCK CAC T T1.1.4
5. PULL PIN OK T T1.1.5
6. SIGNAL START AND UNCOUPLE LOCOMOTIVES SU T E,T T1.1.6
1.2
1. POSITION TRAINMAN AT CUT W T T1.2.1
2. CLOSE ANGLE COCK AT CUT CAC T T1.2.2
3. RELEASE AIR BRAKES RAB E T1.2.3
4. PULL PIN OK T T1.2.4
5. SIGNAL START AND UNCOUPLE CARS SU T E,T T1.2.5
6. RETURN TRAINMAN TO LOCO (2 MAN CR. ONLY) W T T1.2.6
1.3
1. MOVE CUT TO RECEIVING TRACK MT E,T T1.3.1
2. SERVICE APPLICATION SA E T1.3.2
3. SET HAND BRAKES ON 1st FEW CARS SHB T T1.3.3
4. CLOSE LOCO ANGLE COCK CAC T T1.3.4
5. PULL PIN OK T T1.3.5
6. SIGNAL START AND UNCOUPLE LOCOMOTIVES SU T E,T T1.3.6
1.4
1. RETURN LOCO(S) TO WAITING CARS MT E,T T1.4.1
2. SIGNAL STOP SSP T T1.4.2
3. COUPLE TO HEAD CAR CUP E,T T1.4.3
4. CONNECT AIR LINE CH T T1.4.4
5. OPEN LOCO ANGLE COCK OAC T T1.4.5
6. CHARGE BRAKES CBCO E T1.4.6
1.5
1. POSITION TRAINMAN AT CUT W T T1.5.1
2. SET HAND BRAKES ON A FEW CARS OF SECOND CUT SHB T T1.5.2
3. CLOSE ANGLE COCK AT CUT CAC T T1.5.3
4. RELEASE AIR BRAKES E T1.5.4
5. PULL PIN OK T T1.5.5
6. SIGNAL START AND UNCOUPLE CARS SU T E,T T1.5.6
7. RETURN TRAINMAN TO LOCO (2 MAN CR. ONLY) W T T1.5.7
1.6
1. MOVE CUT TO RECEIVING TRACK MT T1.6.1
2. SERVICE APPLICATION E T1.6.2
3. SET HAND BRAKES ON 1st FEW CARS SHB T T1.6.3
4. CLOSE LOCO ANGLE COCK CAC T T1.6.4
5. PULL PIN OK T T1.6.5
6. SIGNAL START AND UNCOUPLE LOCOMOTIVES SU T E,T T1.6.6
1.7
1. RETURN LOCO(S) TO WAITING CARS MT E,T T1.7.1
2. SIGNAL STOP SSP T T1.7.2
3. COUPLE TO HEAD CAR CUP E,T T1.7.3
4. CONNECT AIR LINE CH T T1.7.4
5. OPEN LOCO ANGLE COCK OAC T T1.7.5
6. RELEASE HAND BRAKES RHB T T1.7.6
1.8
1. MOVE CUT TO RECEIVING TRACK MT E,T T1.8.1
2. SERVICE APPLICATION SA E T1.8.2
3. SET HAND BRAKES ON 1st FEW CARS SHB T T1.8.3
4. CLOSE LOCO ANGLE COCK CAC T T1.8.4
5. PULL PIN OK T T1.8.5
6. SIGNAL START AND UNCOUPLE LOCOMOTIVES SU T E,T T1.8.6
Σ
1C
DOES CABOOSE REMAIN WITH CARS ?
P1C,Y
P1C,N
1.9
1. MOVE LOCO(S) TO CABOOSE MT E,T T1.9.1
2. SIGNAL STOP SSP T T1.9.2
3. COUPLE LOCO(S) TO CABOOSE CUP E,T T1.9.3
4. BLEED CABOOSE BRAKES BC T T1.9.4
5. PULL PIN OK T T1.9.5
6. SIGNAL START AND UNCOUPLE CABOOSE SU T E,T T1.9.6
7. REMOVE CABOOSE E,T T1.9.7
Σ
1.10
1. BLUE FLAG TRACK BF C1 T1.10.1
2. WALK AND INSPECT W1 C1 T1.10.2
3. BAD ORDER AS NECC. BOC C1 T1.10.3
4. BLEED BRAKES BC C1 T1.10.4
1


CUT
CAR
UNIT CONSIDERED
HUMP YARD
FLAT YARD
1
2.1
C T
1. MOVE SWITCH ENGINES TO APPROPRIATE RECEIVING TRACK | MT | E,T | T2.1.1
2. SIGNAL STOP | SSP | E,T | T2.1.2
3. COUPLE ENGINE TO CARS | CUP | E,T | T2.1.3
2A
IS CUT CORRECT LENGTH TO BE CLASS-IFIED ?
PY
PN
2.2
1. WALK | W | T | T2.2.1
2. RELEASE HANDBRAKES | RHB | T | T2.2.2
2.3
1. WALK AND RELEASE HANDBRAKES ON FRONT CUT | W RHB
2. WALK AND SET HANDBRAKES ON REAR CUT | W SHB
3. POSITION TRAINMAN AT CUT | W
4. PULL PIN | OK
5. UNCOUPLE CARS | SU
Σ
2.4
1. MOVE CUT TO SWITCH OR HUMP LEAD | MT
2B
DOES CAR REQUIRE SPECIAL HANDLING ?
HUMP YARD
2.6
1. FOLLOW SPECIAL HANDLING PROCEDURE FOR SPECIFIC CASE | SPH
2.5
1. MOVE CUT FORWARD UNTIL NEXT BREAK IS AT HUMP | MC
2. PULL PIN | OK
2C
WILL CARS REQUIRE HAND BRAKING ?
2.7
1. WAIT FOR BRAKEMAN
2. BOARD AND RIDE CAR | BRC
3. SET HANDBRAKE | SHB
2
2D
DOES CAR REQUIRE SPECIAL HANDLING
FLAT YARD
2.9
1. FOLLOW SPECIAL HANDLING PROCEDURE FOR SPECIFIC CASE | SPH
WANT TO OPEN FREE KNUCKLE OF END CAR ?
2.10
1. BACK UP LOCO AND CARS | XOK | T2.10.1
DOES CUT REQUIRE SPECIAL HANDLING ?
2.8
1. BACK UP LOCO AND CARS | BUL
2.11
1. WAIT FOR PIN PULLER | T2.11.1
2. WAIT UNTIL SWITCH IS SET | T2.11.2
3. SIGNAL START | SST | T2.11.3
4. MOVE CUT FORWARD | MC | T2.11.4
5. PULL PIN | OK | T2.11.5
6. SIGNAL STOP | SSP | T2.11.6
7. SLOW AND STOP REMAINDER OF CUT | T2.11.7
2G
WILL CARS REQUIRE HAND BRAKING ?
2.12
1. WAIT FOR BRAKEMAN
2. BOARD AND RIDE CAR | BRC
3. SET HANDBRAKE | SHB
2


CUT
UNIT CONSIDERED
2
3.1
1. MOVE SWITCH ENGINE TO CLASS TRACK
MT
C
T
$T_{3.1.1}$
3.2
1. SIGNAL STOP
2. COUPLE ENGINE TO LEAD CAR
3. RELEASE HANDBRAKES
SSP
CUP
RHB
$T_{3.2.1}$
$T_{3.2.2}$
$T_{3.2.3}$
3A
COUPLER CONDITION ?
P_1
3.3
1. COUPLED
P_2
3.4
2. U.C. (STOPPED SHORT)
P_3
3.5
3. U.C. (REBOUND OPEN–K)
P_4
3.6
4. U.C. (REBOUND CLOSED–K)
P_5
3.7
5. U.C. (BYPASS–HI/LO)
P_6
3.8
6. U.C. (BYPASS–SIDE)
P_7
3.9
7. U.C. (BROKEN COUPLER)
P_8
3.10
8. U.C. (OTHER)
Σ
TRAIN
3.11
1. MOVE BLOCK TO DEPARTURE TRACK
MC
3B
IS THIS 1st BLOCK OF CARS ?
P_Y
P_N
3.12
1. SET HAND BRAKES
2. PULL PIN
3. SIGNAL START AND UNCOUPLE CARS
SHB
OK
SU
$T_{3.12.1}$
$T_{3.12.2}$
$T_{3.12.3}$
3.13
1. SIGNAL STOP
2. COUPLE TO WAITING BLOCK
3. PULL PIN
4. SIGNAL START AND UNCOUPLE CARS
SSP
CUP
OK
SU
$T_{3.13.1}$
$T_{3.13.2}$
$T_{3.13.3}$
$T_{3.13.4}$
3C
DOES TRAIN NEED A CABOOSE ?
3.14
1. MOVE CABOOSE TO END OF TRAIN
2. SIGNAL STOP
3. COUPLE CABOOSE TO CARS
4. CONNECT AIR LINES AND
5. OPEN ANGLE COCKS
6. CLOSE ANGLE COCKS BETWEEN CABOOSE AND LOCO
7. PULL PIN
8. SIGNAL START AND UNCOUPLE LOCO
MC
SSP
CUP
CH
OAC
CAC
OK
SU
$T_{3.14.1}$
$T_{3.14.2}$
$T_{3.14.3}$
$T_{3.14.4}$
$T_{3.14.5}$
$T_{3.14.6}$
$T_{3.14.7}$
$T_{3.14.8}$
3



TRAIN
UNIT CONSIDERED
3
4.1
1. SET BLUE FLAGS BF
2. CLOSE END ANGLE COCKS CAC
3. LACE AIR HOSES CH
C T
$T_{3.15.1}$
$T_{3.15.2}$
$T_{3.15.3}$
4A
METHOD TO CHARGE TRAIN
P
4.2
1. MOVE ROAD LOCO(S) TO HEAD OF TRAIN MT
2. SIGNAL STOP SSP
3. COUPLE ROAD LOCO (S) CUP
4. OPEN ANGLE COCKS OAC
5. CHARGE BRAKES CBT
4.3
1. CONNECT YARD AIR CH
2. CHARGE BRAKES
3. DISCONNECT YARD AIR
4.4
1. BRING IN YARD ENGINE TO CHARGE TRAIN MT
2. CONNECT AIR LINE CH
3. OPEN LOCO ANGLE COCK OAC
4. CHARGE BRAKES CBT
5. CLOSE ANGLE COCKS BETWEEN LOCO AND 1st CAR CAC
6. REMOVE LOCO MT
4.5
1. MOVE ROAD LOCO(S) TO HEAD OF TRAIN MT
2. SIGNAL STOP SSP
3. COUPLE ROAD LOCO(S) CUP
4. OPEN ANGLE COCKS OAC
5. CHARGE BRAKES CBT
4.6
1. MOVE ROAD LOCO(S) TO HEAD OF TRAIN MT
2. SIGNAL STOP SSP
3. COUPLE ROAD LOCO(S) CUP
4. OPEN ANGLE COCKS OAC
5. CHARGE BRAKES CBT
Σ
4.7
1. RELEASE HAND BRAKES
4B
IS B.P.P. AT REAR 60 lb AND WITHIN 15 lb OF FEED VALVE PRESSURE ?
P_Y
P_N
4.9
1. INSPECT TRAIN IT
2. FIX PROBLEM FP
3. CHARGE BRAKES CBT
4.10
1. APPLY 15 lb BP REDUCTION R15
2. LAP BRAKE VALUES LBV
3. MEASURE LEAKAGE RATE LRT
4C
IS LEAKAGE RATE < 5 lb / MIN ?
4.11
1. INSPECT TRAIN IT
2. FIX PROBLEM FP
3. CHARGE BRAKES CBT
4.12
1. FULL SERVICE REDUCTION SA
4.13
INSPECT TRAIN FOR: IT
1. PROPER ANGLE COCK POSITION
2. BRAKE APPLICATION ON EACH CAR
3. CORRECT PISTON TRAVEL
4. BRAKE RIGGING NOT FOULED
5. BRAKE EQUIPMENT PROPERLY SECURED
4.14
1. RELEASE BRAKES CBT
2. INSPECT TRAIN FOR RELEASED BRAKES IT
4D
ARE ALL CARS IN CONSIST OK. ?
4.15
1. INSPECT TRAIN IT
2. FIX PROBLEM FP
3. CHARGE BRAKES CBT
DEPART

COMPUTER LISTING FOR PROGRAM RAIL

```
      PROGRAM RAIL
C
C     IBRIEF: Ø NORMAILY, 1 IF SHORT F
                **ORM OF OUTPUT DESI
                **RED
C     MODBAS: NAME OF FILE FOR BASELIN
                **E   (4 A5)
C     NRES: NUMBER OF RESULTS TO BE OU
                **TPUT
C     MATCH: USE VARIES THROUGHOUT PRO
                **GRAM, ROUGHLY 1 IF
                ** NO ERROR
C           Ø IF ERROR ENCOUNTERED
C     LEVEL: FOR USE BY SUBROUTINE HEL
                **P. TELLS HELP WHIC
                **H MESSAGE TO
C           TYPE.
C     NFILE:  NUMBER OF FILES IN RAIL.
                **DAT  (UNIT 21)
C     NPARM:  NUMBER OF PARAMETERS
C     IMODEL: NAME OF CURRENT MODEL, 4
                **A5
C     IDIR:   COPY OF DIRECTORY
C     PARAM:  CURRENT VALUES OF PARAME
                **TERS
C     RESULT: MOST RECENT RESULTS OF S
                **UBROUTINE PROGRM
C     ICHANG: Ø IF CORRESPONDING ENTRY
                ** IN PARAM HAS NOT
                **BEEN CHANGED
C             SINCE LAST LOAD OPERATIO
                **N (SEE SUBR. LOAD)
C             1 IF CHANGED (SEE SUBR.
                **CHANGE)
C     KEYWD:  5 CHARACTER IDENTIFIER F
                **OR EACH PARAMETER
                **(SUBR. CHANGE)
C     RESNAM: IDENTIFIER FOR RESULT (S
                **UBR. PROGRM)
C     MAP:     POINTER TO RAIL.HLP (SUB
                **R. HELP)
C     MAXHLP: NUMBER OF RECORDS IN RAI
                **L.HLP (SUBR. HELP)
      COMMON /FAC/IBRIEF,MODBAS(4),NRE
                **S
     1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                **(4),IDIR(4,2Ø)
     1/DAT/PARAM(3Ø),RESULT(2Ø),ICHAN
                **G(8Ø)
     2/LST/KEYWD(8Ø),RESNAM(2Ø)
     3/HLP/MAP(2ØØ),MAXHLP
C
      LEVEL=1Ø1
C     RAIL.DAT:          RECORD 1 CONTAIN
                **S NUMBER OF RECORD
                **S TO FOLLOW
C             REMAINING RECORDS CONTAI
                **N SETS OF PARAMETE
                **R VALUES
      OPEN(UNIT=21,DEVICE='DSK',FILE='
                **RAIL.DAT',ACCESS='
                **RANDOM'
     1,MODE='ASCII',RECORD SIZE=1143,
                **ERR=21Ø)
C     RAIL.HLP:          RECORDS 1 TO 8 C
                **ONTAIN MAXHLP, MAP
C             REMAINING RECORDS CONTAI
                **N MESSAGE TO BE OU
                **TPUT BY
C             SUBR. HELP
      OPEN(UNIT=22,DEVICE='DSK',FILE='
                **RAIL.HLP',ACCESS='
                **RANDOM'
     1,MODE='ASCII',RECORD SIZE=76,ER
                **R=2ØØ)
      READ(22#1,1Ø,ERR=23Ø) MAXHLP,(MA
                **P(I),I=1,23)
      READ(22#2,1Ø,ERR=23Ø)  (MAP(I),I=
                **24,47)
      READ(22#3,1Ø,ERR=23Ø)  (MAP(I),I=
                **48,71)
      READ(22#4,1Ø,ERR=23Ø)  (MAP(I),I=
                **72,95)
      READ(22#5,1Ø,ERR=23Ø)  (MAP(I),I=
                **96,119)
      READ(22#6,1Ø,ERR=23Ø)  (MAP(I),I=
                **12Ø,143)
      READ(22#7,1Ø,ERR=23Ø)  (MAP(I),I=
                **144,167)
      READ(22#8,1Ø,ERR=23Ø)  (MAP(I),I=
                **168,191)
1Ø    FORMAT(24I3,4X)
C     UNIT 19 SO OUTPUT CAN BE EASILY
                **SENT TO PRINTER WI
                **TH MINOR
C           PROGRAM CHANGES
15    OPEN(UNIT=19,DEVICE='TTY',ACCESS
                **='SEQINOUT')
C     READ DIRECTORY FROM RAIL.DAT . F
                **IRST 2Ø CHARACTERS
                ** OF EACH
C           FILE IN RAIL.DAT IS THE
                **NAME OF THE FILE.
      CALL REDIR
2Ø    FORMAT(I4)
4Ø    FORMAT(4 A5)
5Ø    TYPE 6Ø
6Ø    FORMAT(' TYPE HELP FOR INSTRUCTI
                **ONS.')
C     SETNAM: SET NRES,NPARM,KEYWD TO
                **RAILROAD VALUES(SU
                **BR. PROGRM)
      CALL SETNAM
C     DLOAD;  LOAD MODEL SPECIFIED BY
                **IMODEL INTO PARAM
                **(SUBR. LOAD)
      CALL DLOAD
C     THIS IS THE CENTRAL POINT OF THE
                ** PROGRAM.
7Ø    TYPE 8Ø
8Ø    FORMAT(' INSTRUCTION:',$)
C     LEVEL EQUALS 1Ø1 ONLY IF PROGRAM
                ** HAS JUST BEEN ENT
                **ERED.
C             A MORE DETAILED MESSAGE
                **SHOULD BE GIVEN FO
                **R THE NEW USER
      IF(LEVEL.NE.1Ø1) LEVEL=1Ø6
C     GET INSTRUCTION FROM USER
      ACCEPT 9Ø,ANS
9Ø    FORMAT(A5)
C     EXECUTE INSTRUCTION
      CALL LOCK(ANS)
C     IF USER'S INSTRUCTION VALID GET
                **NEXT INSTRUCTION
      IF(MATCH.EQ.1) GO TO 7Ø
      IF(ANS.EQ.'STOP') GO TO 11Ø
      TYPE 1ØØ
```

```
100     FORMAT(' NOT A COMMAND. TYPE HEL
                **P FOR A LIST OF CO
                **MMANDS.')
        GO TO 70
C       CHECK THAT USER IS FINISHED WITH
                ** PROGRAM
110     TYPE 120
120     FORMAT(' ARE YOU FINISHED WITH T
                **HE PROGRAM?',$)
        ACCEPT 90,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 RAI
                **L.HLP')
        GO TO 15
210     TYPE 220
220     FORMAT(' ERROR WHILE OPENING RAI
                **L.DAT')
        STOP
230     MAXHLP=8
        DO 240 I=1,200
240     MAP(I)=3
        GO TO 15
        END
C
C
C
C
        BLOCK DATA
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                **(4),IDIR(4,20)
        1/DAT/PARAM(80),RESULT(20),ICHAN
                **G(80)
        2/LST/KEYWD(80),RESNAM(20)
        3/HLP/MAP(200),MAXHLP
        DATA ICHANG/80*0/
        DATA IBRIEF/0/
        DATA MODBAS/'DEFAULT
                ** '/
        DATA IMODEL/'DEFAULT
                ** '/
        END
C
C
C
C       CALL SUBROUTINE SPECIFIED BY USE
                **R
        SUBROUTINE LOOK(JANS)
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                **(4),IDIR(4,20)

5       MATCH=0
        IANS=JANS
        IF(IANS.EQ.'CURRE') CALL LOAD
        IF(IANS.EQ.'BASE') CALL CLOAD
        IF(IANS.EQ.'SETNA') CALL SETNAM
        IF(IANS.EQ.'DELET') CALL DELETE
        IF(IANS.EQ.'DIR') CALL DIR
        IF(IANS.EQ.'DIREC') CALL DIR
        IF(IANS.EQ.'LOAD') CALL LOAD
        IF(IANS.EQ.'CHANG') CALL CHANGE
        IF(IANS.EQ.'STORE') CALL STORE
        IF(IANS.EQ.'HELP') CALL HELP
        IF(IANS.EQ.'CHELP') CALL CHELP
        IF(IANS.EQ.'RUN') CALL DIFF
        IF(IANS.EQ.'LHELP') CALL LHELP
        IF(IANS.EQ.'LIST') CALL LIST
        IF(IANS.EQ.'OUTPU') CALL OUTPUT
        IF(IANS.EQ.'MAPDU') CALL MAPDU
        IF(IANS.EQ.'BRIEF') IBRIEF=1
        IF(IANS.EQ.'NOBRI') IBRIEF=0
        IF(IANS.EQ.'OFFLI') CALL OFFLI
        IF(IANS.EQ.'ONLIN') CALL ONLINE
        IF(MATCH.EQ.1) TYPE 10
10      FORMAT(2X)
20      IANS=0
        RETURN
        END
C
C
C       READ FROM RAIL.HLP AND OUTPUT
        SUBROUTINE HELP
        INTEGER IRHT(3),LWITH(4),HLPFOR(
                **16),IOUT(72),BLANK
                **(15),TEXT(15)
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                **(4),IDIR(4,20)
        1/HLP/MAP(200),MAXHLP
        DATA IRHT/'(', '''' , ' '/
        DATA LWITH/ '''' , ',' , '$' , '
                **)' /    !',$)
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 RECO
                **RDS THAT


C               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               SUBR. OUTPUT,LIST
        ENTRY AHELP(I2)
C       FIND STARTING POINT AS BEFORE
        I=MAP(I2)
C       RECORD NUMBERS LESS THAN 8 ARE N
                **OT MESSAGES
10      IF(I.LE.8) GO TO 50
C       RECORDS GREATER THAN MAXHLP ARE
                **NOT PRESENT
        IF(I.GT.MAXHLP) GO TO 50
C       READ A LINE
        READ(22#I,19,ERR=30) J,IOUT,K
19      FORMAT(I3,72A1,I1)
20      FORMAT(I3,14A5,A2,I1)
        DO 23 L=72,2,-1
23      IF(IOUT(L).NE.' ') GO TO 310
        WRITE(19,300)
300     FORMAT(1X)
        GO TO 27
310     IF(IOUT(L).EQ.'$') GO TO 330
        IF(IOUT(L).EQ.';') L=L-1
        WRITE(19,320) (IOUT(LL),LL=1,L)
320     FORMAT(1X,72A1)
        GO TO 27
```

```
330       L=L-1
          IF(IOUT(L).EQ.';') L=L-1
          ENCODE (80,340,HLPFOR) IRHT,(IOU
                    **T(LL),LL=1,L),LWIT
                    **H
340       FORMAT(80A1)
          WRITE(19,HLPFOR)
          GO TO 27
C         DOLLAR SIGN SUPPRESSES CARRAIGE
                    **RETURN SO USER MAY
                    ** RESPOND
C         K EQUALS 1 ONLY AT END OF CHAIN
                    **OF LINES IN MESSAG
                    **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
                    **IC INFORMATION
30        TYPE 40,LEVEL,I
40        FORMAT(' PROGRAM ERROR. LEVEL=',
                    **I3,'    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.')
          GO TO 25
C
C         CHANGE RESPONSE TO HELP
          ENTRY LHELP
C         PROMPT FOR LEVEL NUMBER FOR MESS
                    **AGE TO BE CHANGED
215       TYPE 220
220       FORMAT(' LEVEL:',$)
          READ(5,230,ERR=25) LEVEL
230       FORMAT(I3)
C
C         CHANGE MESSAGE FOR CURRENT LEVEL
          ENTRY CHELP
C         NEW:     0 IF LINE WILL REPLACE A
                    **N ALREADY EXISTING
                    ** RECORD IN
C                  RAIL.HLP
C                  1 IF NEW RECORD IS CREAT
                    **ED
          NEW=0
C         FIND STARTING POINT IN CHAIN FOR
                    ** EXISTING MESSAGE
                    **(SUBR. HELP)
          K=MAP(LEVEL)
C         K WILL BE LESS THAN 9 ONLY IF NO
                    ** MESSAGE EXISTS
C         ICHMAP: 1 IF MAP HAS CHANGED, 0
                    **IF NO CHANGE MADE
                    **YET
          ICHMAP=0
          IF(K.GT.8) GO TO 65
C         NO MESSAGE EXISTS, CREATE A NEW
                    **RECORD
          MAP(LEVEL)=MAXHLP+1
          NEW=1
C         PROMPT USER FOR MESSAGE
C         MAP HAS CHANGED SO REMEMBER TO C
                    **ORRECT IT WHEN FIN
                    **ISHED
          ICHMAP=1
65        TYPE 70
70        FORMAT(' ENTER A LINE.')
          ACCEPT 80,TEXT
80        FORMAT(14A5,A2)
90        TYPE 100
100       FORMAT(' DO YOU WANT TO ENTER AN
                    **OTHER LINE (A CONT
                    **INUATION)?',$)
C         M:       'NO' IF THIS IS TO BE LA
                    **ST LINE IN MESSAGE
C                  ANYTHING ELSE MEANS YES
          READ(5,110,ERR=90) M
110       FORMAT(A5)
          LAST=0
          IF(M.EQ.'NO') LAST=1
C         IF THIS RECORD IS NEW INCREMENT
                    **MAXHLP
          IF(NEW.EQ.1) GO TO 180
C         READ LOCATION OF NEXT RECORD IN
                    **EXISTING CHAIN
          READ(22#K,20,ERR=200) NEXT,BLANK
                    **,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(NEW.EQ.1.AND.LAST.EQ.1) NEXT=
                    **0
C         WRITE LINE TO RAIL.HLP
130       WRITE(22#K,20,ERR=30) NEXT,TEXT,
                    **LAST
C         IF FINISHED WRAP-UP
          IF(LAST.EQ.1) GO TO 150
C         CHANGE NEXT TO CURRENT AND REPEA
                    **T
          K=NEXT
          GO TO 65
C         WRITE NEW VERSION OF MAP IF IT H
                    **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) (MAP(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) (MAP(I),I=120,14
                    **3)
          WRITE(22#7,290) (MAP(I),I=144,16
                    **7)
          WRITE(22#8,290) (MAP(I),I=168,19
                    **1)
290       FORMAT(24I3,4X)
179       RETURN
C
C         INCREMENT MAXHLP BECAUSE RECORD
                    **IS BEING CREATED
180       MAXHLP=MAXHLP+1
C         SET CURRENT RECORD NUMBER TO NEW
                    **LY CREATED RECORD
```

```
      K=MAXHLP
C     NEXT WILL BE CREATED AT THE NEXT
                **  ROUND
      NEXT=MAXHLP+1
C     NEW LINE HAS BEEN CREATED
      NEW=1
      GO TO 120
C     NEW MESSAGE ENDS ON SAME LINE AS
                ** OLD MESSAGE SO NO
                ** CHANGE MADE
190   IF(LAST.EQ.1) GO TO 130
C     NEW MESSAGE IS LONGER THAN OLD M
                **ESSAGE
      NEXT=MAXHLP+1
      NEW=1
      GO TO 130
C     PRINT DIAGNOSTIC
200   TYPE 210,K
210   FORMAT(' PROGRAM ERROR. READ22 A
                **T  K=',I3)
      GO TO 25
      END
C
C
C
C     MOVE PARAMETERS FROM FILE TO CUR
                **RENT
      SUBROUTINE LOAD
      COMMON /FAC/IBRIEF,MODBAS(4),NRE
                **S
      1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                **(4),IDIR(4,20)
      1/DAT/PARAM(80),RESULT(20),ICHAN
                **G(80)
      2/LST/KEYWD(80),RESNAM(20)
      INTEGER ANS(4)
      GO TO 100
C
C     REST OF PROGRAM CAN TEMPORARILY
                **STORE AND RETREIVE
                ** DATA
      ENTRY ALOAD(I2)
      I=I2
C     SKIP A RECORD BECAUSE FIRST ENTR
                **Y IN RAIL.DAT IS N
                **FILE
5     I=I+1
C     READ PARAMETERS INTO CURRENT FIL
                **ENAME, CURRENT PAR
                **AMETERS
      READ(21#I,10,ERR=50) IMODEL,PARA
                **M,NPARM
10    FORMAT(4A5,80E14.8,I3)
      DO 20 J=1,80
C     RESET ICHANG BECAUSE OLD CHANGES
                ** ARE NO LONGER VAL
                **ID
20    ICHANG(J)=0
40    MATCH=1
      RETURN
50    CALL ERRSNS(I,J)
      TYPE 60,I,J
60    FORMAT(' PROGRAM ERROR IN LOAD.
                ** FIRST=',I3,'     S
                **ECOND=',I3)
      GO TO 40
C     PROMPT USER FOR FILENAME
100   TYPE 110
110   FORMAT(' LOAD VALUES STORED IN F
                **ILE:',$)
115   LEVEL=102
      ACCEPT 120,ANS
120   FORMAT(4A5)
C     FIND FILENAME IN DIRECTORY
      CALL LOCATE(ANS,I)
C     SEE SUBR. LOCATE FOR DESCRIPTION
                ** OF MATCH IN THIS
                **CASE
      GO TO (5,40,100,130) MATCH
C     FILE NOT FOUND IN DIRECTORY, TRY
                ** AGAIN
130   TYPE 140
140   FORMAT(' FILE NOT FOUND.')
      GO TO 100
C
C     LOAD BASE CASE AS SPECIFIED BY M
                **ODBAS
      ENTRY BLOAD
C     FIND CONTENTS OF MODBAS IN DIREC
                **TORY
      CALL ALOC(MODBAS,I)
C     IF NOT FOUND TYPE WARNING
      IF(MATCH.NE.1) GO TO 170
C     SKIP A RECORD BECAUSE OF RAIL.DA
                **T
150   I=I+1
C     DONT CHANGE IMODEL
      READ(21#I,10,ERR=50) MODBAS,PARA
                **M,NPARM
      GO TO 40
C
C     LOAD BASE CASE AS SPECIFIED BY U
                **SER
      ENTRY CLOAD
C     PROMPT FOR FILENAME
160   TYPE 110
      LEVEL=107
165   ACCEPT 120,ANS
      IF(ANS(1).EQ.'STOP') GO TO 40
C     FIND RESPONSE IN DIRECTORY
      CALL LOCATE(ANS,I)
      GO TO (150,40,160,170) MATCH
170   TYPE 190
      GO TO 165
190   FORMAT(' THE FILE SPECIFIED FOR
                **BASE CASE IS NOT F
                **OUND.',/
      1,' PLEASE REENTER OR TYPE STOP:
                **',$)
C
C     LOAD AS SPECIFIED BY IMODEL
      ENTRY DLOAD
C     FIND NAME OF CURRENT MODEL IN DI
                **RECTORY
      CALL ALOC(IMODEL,I)
C     IF NOT FOUND GIVE WARNING
      IF(MATCH.NE.1) GO TO 200
C     LOAD VALUES IN FILE
      GO TO 5
200   TYPE 210
210   FORMAT(' FILE SPECIFIED FOR CURR
                **ENT MODEL NOT FOUN
                **D.',/
      1,' PLEASE REENTER OR TYPE STOP:
                **',$)
      GO TO 115
C
C     LOAD STORED VALUES OF ICHANG
      ENTRY LDCHNG(I3)
      I=I3+1
```

```
C         SEE SUBR. DIFF FOR REASON FOR ST
                    **ORING ICHANG
          READ(21#I,220,ERR=50) ANS,ICHANG
220       FORMAT(4A5,80I1,1043X)
          GO TO 40
          END
C
C
C
C
C         CHANGE VALUE OF A PARAMETER
C         THIS SUBROUTINE SEARCHES THE LIS
                    **T KEYWD(80) FOR TH
                    **E KEYWORD
C         THAT THE USER ENTERS. IF IT IS F
                    **OUND CALL AHELP TO
                    ** TYPE THE
C         QUESTION CORRESPONDING TO THE KE
                    **YWORD. THE USER TH
                    **EN ENTERS
C         THE NEW VALUE AND RETURNS TO THE
                    ** CALLING SUBROUTIN
                    **E. IF THE
C         USERS RESPONSE IS NOT A NUMBER ,
                    **REREAD THE RESPONS
                    **E AND STOP
C         CHECK IT AGAINST KEYWD  WHICH WI
                    **LL RESULT IN A WAR
                    **NING
C         MESSAGE. ENTRY BCHNGE IS TO ALLO
                    **W THE ABBREVIATED
                    **FORM
C         C <KEYWORD> INSTEAD OF CHANGE <R
                    **ETURN> <KEYWORD>.
                    **THIS IS
C         DONE BY THE REREAD IN SUBR. LOOK
          SUBROUTINE CHANGE
          COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
          1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    **(4),IDIR(4,20)
          1/DAT/PARAM(80),RESULT(20),ICHAN
                    **G(80)
          2/LST/KEYWD(80),RESNAM(20)
          INTEGER TEXT(15)
          GO TO 10
          ENTRY BCHNGE(IWORD)
          IANS=IWORD
          GO TO 35
10        TYPE 20
20        FORMAT(' KEYWORD OF PARAMETER:',
                    **$)
          LEVEL=103
          ACCEPT 30,IANS
30        FORMAT(A5)
          IF(IANS.EQ.'STOP') GO TO 125
          CALL LOOK(IANS)
          IF(MATCH.EQ.1) GO TO 10
35        IF(IANS.EQ.'     ') GO TO 125
          DO 50 I=1,80
          IF(IANS.NE.KEYWD(I)) GO TO 50
C
C         SUCCESSFUL SEARCH
          GO TO 100
50        CONTINUE
C
C         KEYWD NOT FOUND
          TYPE 60
60        FORMAT(' THE KEYWORD YOU ENTERED
                    ** IS NOT ON THE LIS
                    **T. TYPE '
          1,'LIST FOR A LIST',/,' OF KEYWO
                    **RDS. TYPE STOP IF
                    **YOU DO NOT'
          2,' WANT TO CHANGE A PARAMETER.'
                    **)
          GO TO 10
C
C         TYPE QUESTION, READ ANSWER
100       CALL AHELP(I)
110       READ(5,120,ERR=130) X
120       FORMAT(E14.0)
          PARAM(I)=X
          ICHANG(I)=1
125       MATCH=1
          RETURN
C
C         READ ERROR
130       LEVEL=I
          ACCEPT 30,IANS
          IF(IANS.EQ.'STOP') GO TO 125
          CALL LOOK(IANS)
          IF(MATCH.EQ.1) GO TO 100
          GO TO 35
          END
C
C
C
C         OUTPUT RESULTS
          SUBROUTINE OUTPUT
          COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
          1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    **(4),IDIR(4,20)
          1/DAT/PARAM(80),RESULT(20),ICHAN
                    **G(80)
          2/LST/KEYWD(80),RESNAM(20)
          TYPE 10,IMODEL
10        FORMAT('     MODEL USED: ',4A5,//
          1,' THE FOLLOWING PARAMETERS HAV
                    **E BEEN CHANGED:')
          DO 30 I=1,NPARM
          IF(ICHANG(I).EQ.0) GO TO 30
          TYPE 20,KEYWD(I),PARAM(I)
20        FORMAT(2X,A5,3X,F14.2,2X,$)
          J=I
          IF(IBRIEF.EQ.1) GO TO 25
          CALL AHELP(J)
25        TYPE 35
35        FORMAT(2X)
30        CONTINUE
          TYPE 40,MODBAS
40        FORMAT(//,' BASE CASE: ',4A5
          1,/,' USING THESE PARAMETERS THE
                    ** FOLLOWING RESULTS
                    ** ARE '
          1,'OBTAINED.')
          DO 50 I=1,NRES
          TYPE 20,RESNAM(I),RESULT(I)
          J=I+80
          IF(IBRIEF.EQ.0) GO TO 45
          TYPE 35
          GO TO 50
45        CALL AHELP(J)
50        CONTINUE
          TYPE 70
```

```
70      FORMAT(////)
        MATCH=1
        RETURN
        END
C
C
C
C
C       LIST CURRENT VALUE OF ALL PARAME
                    **TERS
        SUBROUTINE LIST
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    ** (4) ,IDIR(4,20)
        1/DAT/PARAM(80) ,RESULT(20),ICHAN
                    **G (80)
        2/LST/KEYWD(80) ,RESNAM(20)
        TYPE 4,IMODEL,MODBAS
4       FORMAT(///,' CURRENT MODEL: ',4A
                    **5 ,/
        1,' BASE CASE: ',4A5)
        TYPE 5
5       FORMAT(/,' KEYWORD   VALUE',/)
        IF(NPARM.GE.1) GO TO 30
        TYPE 10
10      FORMAT(' PROGRAM ERROR. NPARM LE
                    **SS THAN 1')
20      MATCH=1
        RETURN
30      DO 50 I=1,NPARM
        TYPE 35,KEYWD(I),PARAM(I)
35      FORMAT(1X,A5,1X,F14.4,2X,$)
        J=I
        IF(IBRIEF.EQ.1) GO TO 36
        CALL AHELP(J)
36      TYPE 40
40      FORMAT(1X)
50      CONTINUE
        GO TO 20
        END
C
C
C
C       PRINT DIRECTORY
        SUBROUTINE DIR
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    ** (4) ,IDIR(4,20)
        1/DAT/PARAM(80) ,RESULT(20),ICHAN
                    **G (80)
        2/LST/KEYWD(80) ,RESNAM(20)
        IF(NFILE.LE.0) GO TO 40
        DO 10 I=1,NFILE
10      TYPE 20,I,(IDIR(J,I),J=1,4)
20      FORMAT(1X,I2,5X,4A5)
30      MATCH=1
        RETURN
40      TYPE 50
50      FORMAT(/,'  DIRECTORY IS EMPTY.'
                    **,/)
        NFILE=0
        GO TO 30
        END
C
C
C
C       FIND LOCATION OF FILE IN DIRECTO
                    **RY
```

```
        SUBROUTINE LOCATE(ANS,I)
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    ** (4) ,IDIR(4,20)
        1/DAT/PARAM(80) ,RESULT(20),ICHAN
                    **G (80)
        2/LST/KEYWD(80) ,RESNAM(20)
        INTEGER ANS(4)
10      IF(ANS(1).EQ.'STOP') GO TO 60
        CALL LOOK(ANS(1))
        IF(MATCH.EQ.1) GO TO 70
        ENTRY ALOC(ANS,I)
        DO 30 I=1,NFILE
        DO 20 J=1,4
20      IF(ANS(J).NE.IDIR(J,I)) GO TO 30
        GO TO 50
30      CONTINUE
        GO TO 80
C
C       FOUND
50      MATCH=1
        RETURN
C
C       STOP
60      MATCH=2
        RETURN
C
C       REPEAT PROMPT
70      MATCH=3
        RETURN
C
C       NOT FOUND
80      MATCH=4
        RETURN
        END
C
C
C
C       STORE CURRENT PARAMETERS IN FILE
        SUBROUTINE STORE
        COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
        1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    ** (4) ,IDIR(4,20)
        1/DAT/PARAM(80) ,RESULT(20),ICHAN
                    **G (80)
        2/LST/KEYWD(80) ,RESNAM(20)
        INTEGER ANS(4)
        GO TO 100
        ENTRY ASTORE(I2)
        I=I2
10      I=I+1
        WRITE(21#I,20,ERR=50) IMODEL,PAR
                    **AM,NPARM
20      FORMAT(4A5,80E14.8,I3)
40      MATCH=1
        RETURN
50      TYPE 51
51      FORMAT(' PROGRAM ERROR IN STORE.
                    **')
        GO TO 40
100     TYPE 110
110     FORMAT(' STORE IN FILE CALLED:',
                    **$)
        LEVEL=104
        ACCEPT 120,ANS
120     FORMAT(4A5)
        CALL LOCATE(ANS,I)
        GO TO (10,40,130,130) MATCH
```

```
130       NFILE=NFILE+1
          I=NFILE
          DO 140 J=1,4
          IDIR(J,I)=ANS(J)
140       IMODEL(J)=ANS(J)
          WRITE(21#1,995) NFILE
995       FORMAT(I3,1140X)
          GO TO 10
C
C         STORE CURRENT VALUES OF ICHANG
          ENTRY STRCHG(I3)
150       I=I3+1
160       WRITE(21#I,180,ERR=50) IMODEL,IC
                    **HANG
180       FORMAT(4A5,80I1,1043X)
170       GO TO 40
          END




C
C
C
C         READ THE DIRECTORY FROM UNIT 21
          SUBROUTINE REDIR
          COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
          1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    **(4),IDIR(4,20)
20        FORMAT(4A5,1123X)
5         FORMAT(I3,1140X)
          READ(21#1,5,ERR=200) NFILE
          IF(NFILE.LE.0) GO TO 30
          DO 120 I=2,NFILE+1
120       READ(21#I,20,ERR=100) (IDIR(J,I-
                    **1),J=1,4)
          GO TO 30
200       NFILE=0
30        MATCH=1
          RETURN
100       TYPE 110
110       FORMAT(' PROGRAM ERROR IN REDIR.
                    **')
          GO TO 200
          END
C
C
C
C
C         REMOVE A FILE FROM THE DIRECTORY
          SUBROUTINE DELETE
          COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
          1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    **(4),IDIR(4,20)
          INTEGER ANS(4)
          DIMENSION XPARAM(80)
          GO TO 10
          ENTRY ADEL(I2)
          I=I2
          GO TO 50
10        TYPE 20
20        FORMAT(' DELETE FILE NAMED:',$)
          LEVEL=105
          ACCEPT 30,ANS
30        FORMAT(4A5)
          CALL LOCATE(ANS,I)
          GO TO (50,40,10,90) MATCH
40        MATCH=1
          RETURN
```

```
50        IF(I.LT.NFILE) GO TO 60
          NFILE=NFILE-1
          WRITE(21#1,995) NFILE
          GO TO 40
60        NFILE=NFILE-1
          WRITE(21#1,995) NFILE
995       FORMAT(I3,1140X)
          DO 80 J=I+1,NFILE+1
          K=J+1
          READ(21#K,70,ERR=110) ANS,XPARAM
                    **,MPARM
70        FORMAT(4A5,80E14.8,I3)
          WRITE(21#J,70) ANS,XPARAM,MPARM
80        CONTINUE
          CALL REDIR
          GO TO 40
90        TYPE 101
101       FORMAT(' FILE NOT FOUND.')
          GO TO 10
110       CALL ERRSNS(I,J)
          TYPE 120,K,I,J
120       FORMAT(' PROGRAM ERROR IN DELETE
                    **. K=',I3,' I=',I3,
                    **' J=',I3)
          GO TO 40
          END
C
C
C
C         DO SIMULATION
          SUBROUTINE PRGRM
          IMPLICIT REAL(A-Z)
          INTEGER I,NRES,MATCH,LEVEL,NFILE
                    **,IMODEL,IDIR,NAM,R
                    **ESNAM
          1,NPARM,ICHANG
          REAL T(9)
          COMMON /FAC/IBRIEF,MODBAS(4),NRE
                    **S
          1,MATCH,LEVEL,NFILE,NPARM,IMODEL
                    **(4),IDIR(4,20)
          2/LST/NAM(80),RESNAM(20)
          3/DAT/P1AY,P1BY,P1CY,HBT,HBC,CPT
                    **,LPT,SHB,FHB,WIC,C
                    **AC
          1,OAC,OK,CH,SU,SSP,CUP,RAB,CBTO,
                    **CBCC,CBT70,CBC70,R
                    **C,MT,SA,P2AY
          2,P2BY,P2CY,HBCC,CUTPT,ACL,VHC,P
                    **3A(9),P3BY,P3CY,P3
                    **DFD,P3DY,P3DYE
          3,CTPDT,P4AY,P4BY,P4CY,RCSZ,YCSZ
                    **,CI,RLPT,RLAB,RRLC
                    **C,RSE,RC
          4,NULL(22)
          8,URC,UYC,UCI,URL,USE,UC,CURC,CU
                    **YC,CUCI,CUL,CUSE,C
                    **UC,NULL1(8)
          8,ICHANG(80)
C
C
C         EQUATIONS
C         CHECK FOR DIVIDE BY ZERO
10        IF(VHC.EQ.0.0) GO TO 200
          IF(CPT.EQ.0.0) GO TO 210
          IF(CTPDT.EQ.0.0) GO TO 220
C         YARD TRAIN
          T11=MT+SA+HBT*(SHB+2*WIC)+CAC+OK
                    **+SU
          T12=WIC*CPT/2+CAC+RAB+OK+SU
```

```
      T13 =MT+SA+HBC*(SHB+2*WIC) +CAC+OK
     **+SU
      T14 =MT+SSP+CUP+CH +OAC+CBCO
      T15 =WIC*CPT/2+HBC*(SHB +2*WIC) +CA
     **C +RAB +OK +SU
      T16 =T13
      T17 =MT+SSP+CUP+CH +OAC+HBC*(RHB+2
     ***WIC)
      T18 =MT+SA+HBC*(SHB+2*WIC) +CAC+OK
     **+SU
      T19 =MT+SSP+CUP+EC+OK+SU
      T11Ø= BC*CPT
      TY=P1A1*T11+(1-P1A1)*((P1BY*(T12
     **+T14) +(1-P1BY)*(T1
     **5+T17))
     1 +T13 +T18) + (1-P1CY) *T19
      TI=T11Ø
      T1=TY+TI
C
C     CLASSIFICATION-HUMP YARD
      T21=MT+SSP+CUP
      T22 =HBC* (RHB+2 * WIC)
      CPC=CPT/CUTPT
      T23 =HBC* (RHB+WIC) +WIC*CPC+HBC*(S
     **HB+WIC) +OK+SU
      T24 =MT
      T25 =ACL/(VHC*88)
      T26 =1Ø
      T27 =3Ø
      TPCUT=T21+P2AY*T22+ (1-P2AY) *T23 +
     **T24
      TCS=P2BY*T26+ (1-P2BY) *T25
      T2=CUTPT*TPCUT+CPT*TCS
C
C     PULL DOWN AND CHARGE BRAKES
      T31=MT
      T32 =SSP+CUP+HBC*RHB
      T(1) =Ø
      T(2) =5
      T(3) =5
      T(4) =5
      T(5) =15
      T(6) =15
      T(7) =6Ø
      T(8) =5
      T(9) =Ø
      T33 =Ø
      DO 4Ø I=1,9
4Ø    T33 =T33 + P3A(I)* T(I)
      T33CT =(T33+WIC) *CPT/CTPDT
      T34 =MT
      T35 =HBT*(SHB+2*WIC) +OK+SU
      T36 =SSP+CUP+OK+SU
      T37 =MT+SSP+CUP+CH +2*OAC+WIC +CAC +
     **OK+SU
      T38 =CPT* (WIC+CH) +CAC
      T39 =MT+SSP+CUP+ CH +OAC+CBTC
      T31Ø=2Ø
      T311=MT+CH+OAC+CB1O +CAC+MT
      T312=MT+SSP+CUP+CH+CAC+CBT7Ø
      T313=HBT*(2*WIC +RHB)
      TPD=T31 + T32 +T33 +T34 +P3BY*T35+(1-
     **P3BY) *T36+P3CY*T37
     **+T38
      TRCL=P3DRD*T39+ (1-P3DRD) *T312+T3
     **13
      TYA=P3DY*T312
      TYE=P3DYE*T311
      T3= TPD+ TRCL+TYA+TYE
```

```
C
C     POWER BRAKE TEST
      T41=1Ø
      T42 =3Ø
      T43 =5
      T44 =3Ø
      T45 =2Ø
      T46 =2Ø
      T47=3Ø
      T4=T41+ (1-P4AY) *T42 +T43 + (1-P4BY)
     *** T44+T45+T46+ (1-P4
     **CY) *T47
C
C     COST EQUATIONS
      URC=5Ø6.346*(TY +TRCL+T4) *RCSZ/CP
     **T
      UYC=5Ø6.346*YCSZ*(T2+TPD+TYE) /CP
     **T
      UCI=5Ø6.346*(CI *TI+CPT*P2CY*T27+
     **P3DY*TYA)/CPT
      URL=1Ø12692*RLPT*(TY+TRCL+T4) /CP
     **T
      USE=1Ø12692*(T2+TPD+TYE) /CPT
      UC=1Ø12692* (T1+Ø.5* ((CUTPT+1) *TP
     **CUT +CPT*TCS) +T3+T4
     **)
      CURC=RLAE*URC
      CUYC=RLAE*UYC
      CUCI=RLAE*UCI
      CURL=RRLCC*URL
      CUSE=RSE*USE
      CUC =RC*UC
C
5Ø    MATCH=1
      RETURN
      ENTRY SETNAM
C     SET VALUES FOR MODEL SPECIFIC VA
     **RIABLES
      NPARM =58
      NRES=12
      NAM(1) = 'P1A1'
      NAM(2) = 'P1BY'
      NAM(3) = 'P1CY'
      NAM(4) = 'HBT'
      NAM(5) = 'HBC'
      NAM(6) = 'CPT'
      NAM(7) = 'IPT'
      NAM(8) = 'SHB'
      NAM(9) = 'RHB'
      NAM(1Ø) = 'WIC'
      NAM(11) = 'CAC'
      NAM(12) = 'OAC'
      NAM(13) = 'OK'
      NAM(14) = 'CH'
      NAM(15) = 'SU'
      NAM(16) = 'SSP'
      NAM(17) = 'CUP'
      NAM(18) = 'RAB'
      NAM(19) = 'CBTO'
      NAM(2Ø) = 'CBCO'
      NAM(21) = 'CBT7Ø'
      NAM(22) = 'CBC7Ø'
      NAM(23) = 'BC'
      NAM(24) = 'MT'
      NAM(25) = 'SA'
      NAM(26) = 'P2AY'
      NAM(27) = 'P2BY'
      NAM(28) = 'P2CY'
      NAM(29) = 'HBCC'
      NAM(3Ø) = 'CUTPT'
      NAM(31) = 'ACL'
```

```
      NAM(32)='VHC'
      NAM(33)='P3A-1'
      NAM(34)='P3A-2'
      NAM(35)='P3A-3'
      NAM(36)='P3A-4'
      NAM(37)='P3A-5'
      NAM(38)='P3A-6'
      NAM(39)='P3A-7'
      NAM(4Ø)='P3A-8'
      NAM(41)='P3A-9'
      NAM(42)='P3BY'
      NAM(43)='P3CY'
      NAM(44)='P3DRD'
      NAM(45)='P3DY'
      NAM(46)='P3DYE'
      NAM(47)='CTPDT'
      NAM(48)='P4AY'
      NAM(49)='P4BY'
      NAM(5Ø)='P4CY'
      NAM(51)='RCSZ'
      NAM(52)='YCSZ'
      NAM(53)='CI'
      NAM(54)='RLPT'
      NAM(55)='RLAB'
      NAM(56)='RRLOC'
      NAM(57)='RSF'
      NAM(58)='RC'
      RESNAM(1)='URC'
      RESNAM(2)='UYC'
      RESNAM(3)='UCI'
      RESNAM(4)='URL'
      RESNAM(5)='USE'
      RESNAM(6)='UC'
      RESNAM(7)='CURC'
      RESNAM(8)='CUYC'
      RESNAM(9)='CUCI'
      RESNAM(1Ø)='CUL'
      RESNAM(11)='CUSE'
      RESNAM(12)='CUC'
      DO 1ØØ I=1,8Ø
1ØØ   ICHANG(I)=Ø
      RETURN
2ØØ   TYPE 2Ø1
2Ø1   FORMAT(' VHC EQUALS ZERO. NO COM
          **PUTATION DONE.')
      TYPE 222
      GO TO 5Ø
21Ø   TYPE 211
211   FORMAT(' CPT EQUALS ZERO. NO COM
          **PUTATION DONE.')
      TYPE 222
      GO TO 5Ø
22Ø   TYPE 221
221   FORMAT(' CTPDT EQUALS ZERO. NO C
          **OMPUTATION DONE.')
      TYPE 222
222   FORMAT(' VHC,CPT, AND CTPDT CANN
          **OT EQUAL ZERO BECA
          **USE THEY',/
      1,' APPEAR IN A DIVISION.')
      END
C
C
C
CC    LIST CONTENTS OF HELP FILE
      SUBROUTINE MAPDU
      COMMON /FAC/IBRIEF,MODBAS(4),NRE
          **S
      1,MATCH,LEVEL,NFILE,NPARM,IMODEL
          **(4),IDIR(4,2Ø)
      1/HLP/MAP(2ØØ),MAXHLP
      DO 2Ø I=1,2ØØ
      IF(MAP(I).LE.Ø) GO TO 2Ø
      TYPE 1Ø,I
1Ø    FORMAT(/,' LEVEL=',I3)
      J=I
      CALL AHELP(J)
2Ø    CONTINUE
      MATCH=1
      RETURN
      END
C
C
C
C     CALL PROGRAM, DO DIFFERENCING
      SUBROUTINE DIFF
      DIMENSION XRES(2Ø)
      COMMON /FAC/IBRIEF,MODBAS(4),NRE
          **S
      1,MATCH,LEVEL,NFILE,NPARM,IMODEL
          **(4),IDIR(4,2Ø)
      1/DAT/PARAM(8Ø),RESULT(2Ø),ICHAN
          **G(8Ø)
C
C     STORE CURRENT VALUES
      NFILE=NFILE+2
      J=NFILE-1
      CALL ASTORE(J)
      CALL STRCHG(J+1)
C
C     COMPUTE BASE CASE
      CALL BLOAD
5     CALL PRGFM
      DO 1Ø I=1,NRES
1Ø    XRES(I)=RESULT(I)
C
C     COMPUTE CURRENT MODEL
      CALL ALOAD(J)
15    CALL PRGFM
      CALL LDCHNG(J+1)
      CALL ADEL(J+1)
      CALL ADEL(J)
C
C     COMPUTE DIFFERENCES
      DO 2Ø I=1,NRES
2Ø    RESULT(I)=RESULT(I)-XRES(I)
      CALL OUTPUT
      MATCH=1
      RETURN
      END
C
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='SEQOUT')
      RETURN
C
C     RESTORE OUTPUT TO TERMINAL
      ENTRY ONLINE
      CLOSE(UNIT=19)
      OPEN(UNIT=19,DEVICE='TTY',ACCESS
          **='SEQINOUT')
      RETURN
      END
C
C
C
```

APPENDIX B

FINANCIAL MODEL

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, askes 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.

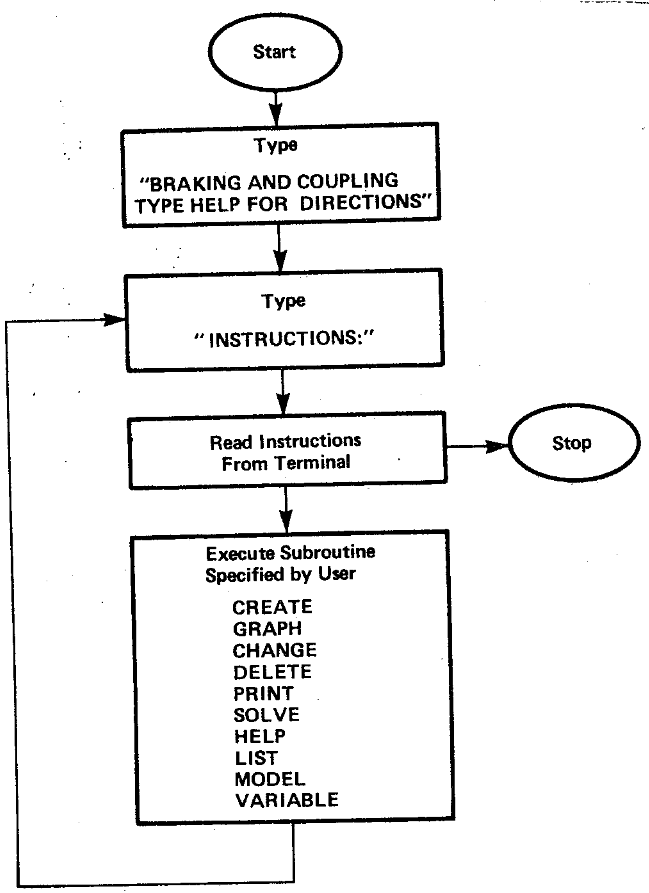


FIG. B.1. FINANCIAL MODEL FLOWCHART.

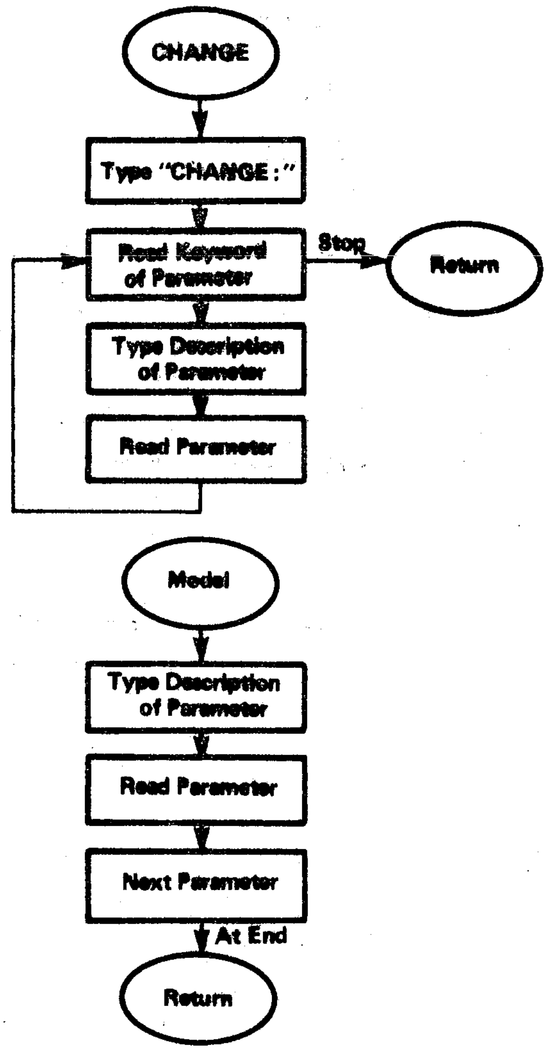


FIG. B.1 *(Cont.)*. FINANCIAL MODEL FLOWCHART.

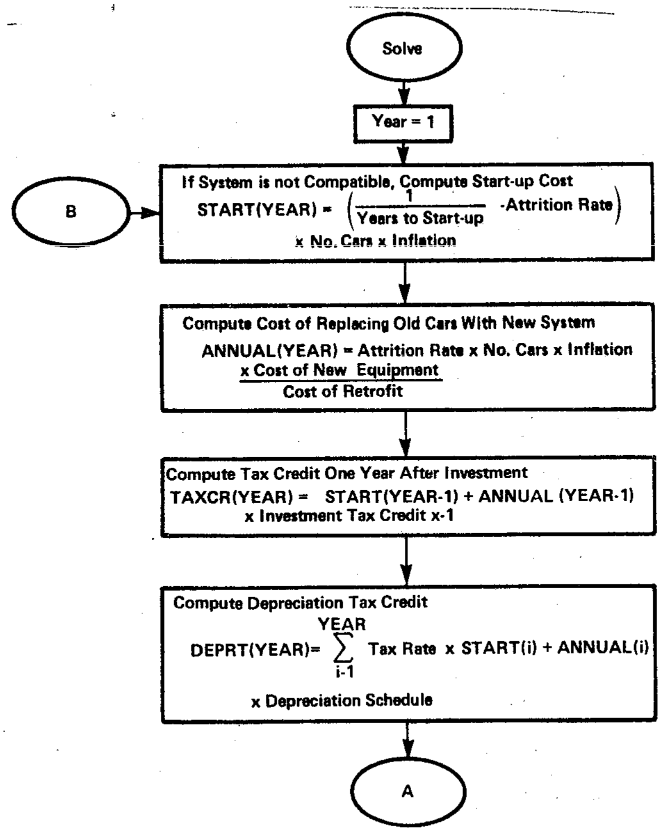


FIG. B.1 *(Cont.)*. FINANCIAL MODEL FLOWCHART.

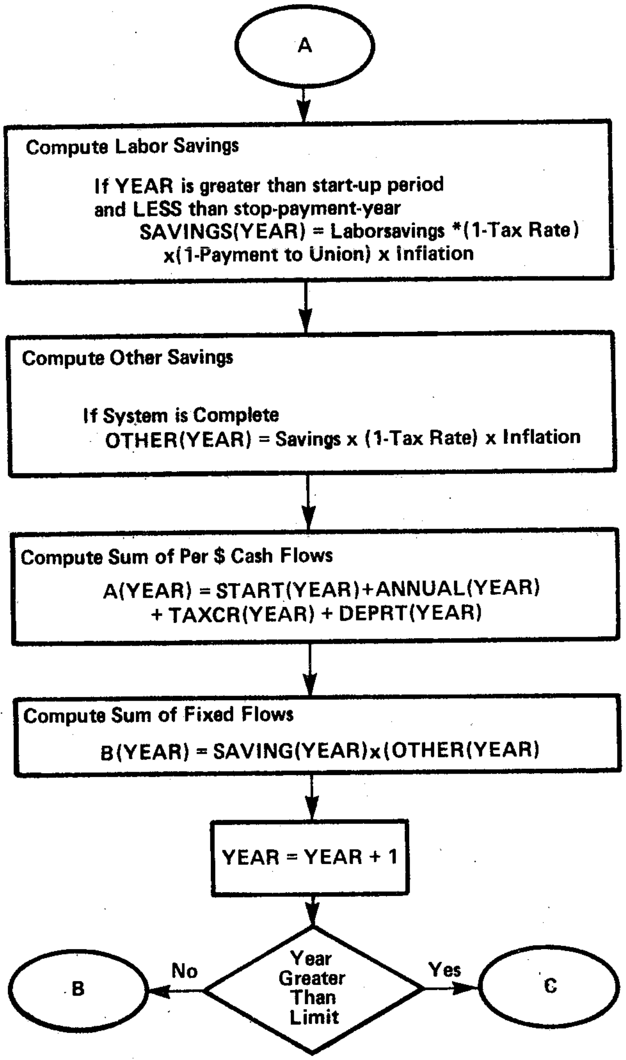


FIG. B.1 *(Cont.)*. FINANCIAL MODEL FLOWCHART.

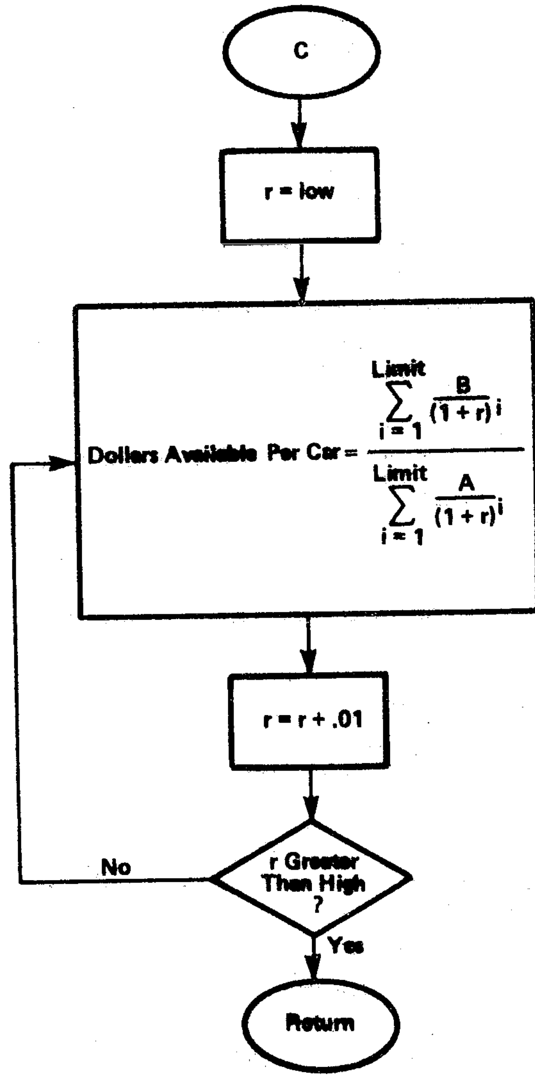


FIG. B.1 *(Cont.)*. FINANCIAL MODEL FLOWCHART.

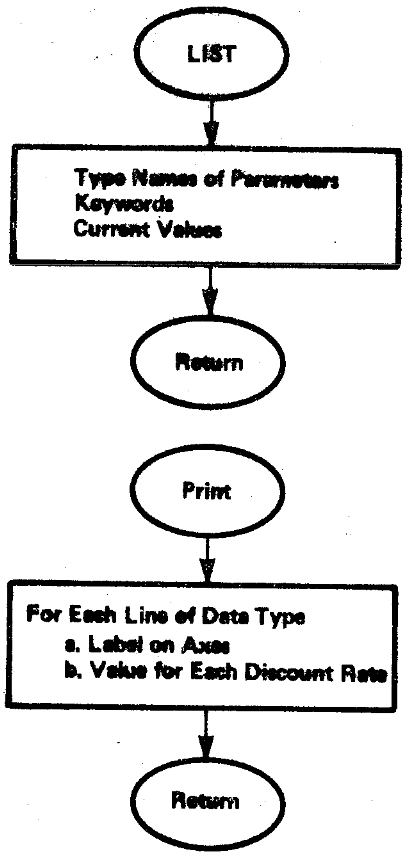


FIG. B.1 *(Cont.)*. FINANCIAL MODEL FLOWCHART.

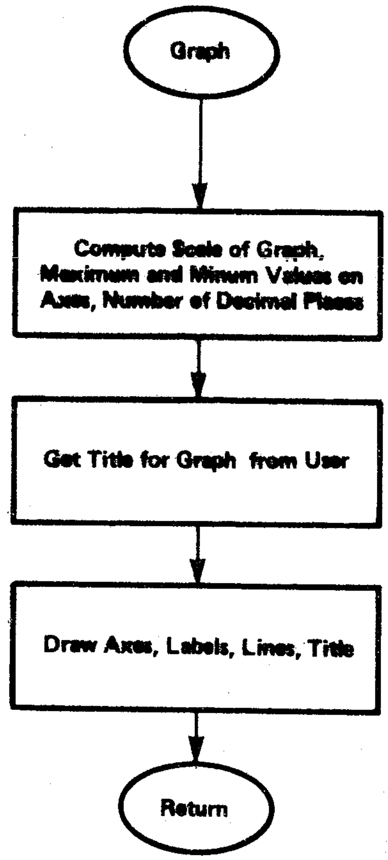


FIG. B.1 *(Cont.)*. FINANCIAL MODEL FLOWCHART.

```
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?.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?.25
WHAT IS THE ANNUAL SAVINGS NOT SUBJECT TO
UNION PAYOUT?0
WHAT IS THE TAX RATE FOR THE RAILROAD INDUSTRY?.46
WHAT FRACTION OF INVESTMENTS ARE DEDUCTIBLE FOR
INVESTMENT TAX CREDIT?.10
WHAT IS THE INFLATION RATE FOR:
MATERIALS (IN PERCENT)?10
LABOR (IN PERCENT)?8.7
SAVINGS NOT SUBJECT TO UNION PAYOUT (IN PERCENT)?10
WHAT IS THE LIFETIME OF THE ASSET?16
WHICH METHOD OF DEPRECIATION DO YOU WANT TO USE?
          STRAIGHT      -STRAIGHT LINE
          DOUBLE        -DOUBLE DECLINING BALANCE
          SUM           -SUM OF YEARS DIGITS
```

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

```
VARIABLE                               KEYWORD          CURRENT VALUE
NUMBER OF YEARS IN ANALYSIS             LIMIT                   21
YEARS BEFORE SYSTEM IS COMPATIBLE       COMPATIBLE               5
NUMBER OF CARS                          NUMBER         1700000.000
ATTRITION RATE                          ATTRITION            0.037
NEW COST OF EQUIPMENT                   FRACTION             0.500
INVESTMENT TAX CREDIT                   INVESTMENT           0.100
TAX RATE                                TAX                  0.460
LOSS TO UNION                           UNION                0.250
LABOR SAVINGS                           SAVINGS      220000000.000
YEARS SAVINGS ARE LOST TO UNION         LOSE                    10
OTHER SAVINGS                           OTHER                0.000
INFLATION:                              INFLATION
      MATERIALS                                              1.100
      LABOR                                                  1.087
      OTHER                                                  1.100
MINIMUM DISCOUNT RATE                   RATES                    5
MAXIMUM DISCOUNT RATE                   RATES                   25
DEPRECIATION                            DEPRECIATION
       LIFETIME OF ASSETS                                       16
       SUM OF YEARS DIGITS DEPRECIATION USED.
```

FIG. B.3. EXAMPLE MODEL INPUTS.

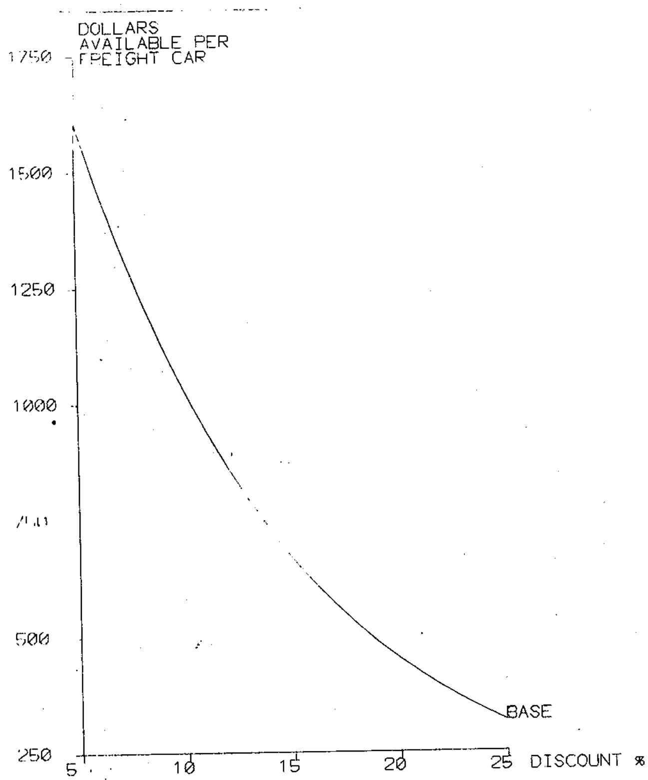


FIG. B.4. EXAMPLE OF GRAPHIC MODEL OUTPUT.

COMPUTER LISTING FOR FINANCIAL MODEL

```
      PROGRAM BRAKE
      COMMON LINES,DATA(26,2,10),POINT
                **(10),LABEL(10,2),W
                **IDTH(2)
      1,YLABEL(40),XLABEL(2),LIMIT,ICO
                **MP,X,NCAR,ATTRAT,M
                **ATINF
      2,LABINF,LABORS,LOW,HIGH,PAYSTP,
                **FRAC,FRIDT,TAXRAT,
                **UPAYRT
      3,SCHED(25),SNSUP,OINF,METHOD,LI
                **FE
      REAL NCAR,MATINF,LABINF,LABORS
      INTEGER POINT,YEAR,HIGH,LOW,PAYS
                **TP
      LEVEL=1
      CALL PLOTS('GRF')
      TYPE 10
10    FORMAT(' BRAKING AND COUPLING',/
                **,' TYPE HELP FOR D
                **IRECTIONS.')
20    TYPE 30
30    FORMAT('  INSTRUCTION:',$)
      ACCEPT 40,ANS
40    FORMAT(A5)
      IMATCH=0
      IF(LEVEL.GT.2) LEVEL=2
      CALL LOOK(IMATCH,ANS,LEVEL)
      IF(ANS.EQ.'STOP') GO TO 50
      IF(IMATCH.EQ.0) GO TO 70
      GO TO 20
50    TYPE 51
51    FORMAT(' ARE YOU FINISHED WITH T
                **HE PROGRAM?',$)
      ACCEPT 40,ANS
      IF(ANS.NE.'YES') GO TO 20
      TYPE 60
60    FORMAT(' FINISHED. TURN ON PLOTT
                **ER AND TYPE THE FO
                **LLOWING.'/
      2,' ASS PLT: (RETURN)',/
      2,' COP GRF (ESCAPE) ... (T0) PL
                **T: (RETURN) (RETUR
                **N)',/
      3,' DEA PLT: (RETURN)')
      CALL PLTEND
      STOP
70    TYPE 80

80    FORMAT(' PLEASE CHECK THE COMMAN
                **D YOU USED. TO CHA
                **NGE A',/
      1,' PARAMETER YOU MUST FIRST TYP
                **E CHANGE. TYPE HEL
                **P FOR',/
      2,' MORE INSTRUCTIONS.')
      GO TO 20
      STOP
      END
```

```
C
C
C
C     MODIFY PARAMETERS
      SUBROUTINE CHANG($,MATCH)
      COMMON LINES,DATA(26,2,10),POINT
                **(10),LABEL(10,2),W
                **IDTH(2)
      1,YLABEL(40),XLABEL(2),LIMIT,ICO
                **MP,X,NCAR,ATTRAT,M
                **ATINF
      2,LABINF,LABORS,LOW,HIGH,PAYSTP,
                **FRAC,FRIDT,TAXRAT,
                **UPAYRT,
      3SCHED(25),SNSUP,OINF,METHOD,LIF
                **E
      REAL NCAR,MATINF,LABINF,LABORS
      INTEGER POINT,YEAR,HIGH,LOW,PAYS
                **TP
      MATCH=1
C
C     TYPE HEADING
10    TYPE 20
20    FORMAT(' TYPE LIST FOR A LIST OF
                ** PARAMETERS THAT C
                **AN BE ',/
      2,' MODIFIED. TO CHANGE A PARAME
                **TER TYPE ITS KEYWO
                **RD ',/
      3,' AFTER THE PROMPT. WHEN FINIS
                **HED TYPE STOP.')
30    TYPE 40
      LEVEL=17
40    FORMAT(' CHANGE:',$)
      ACCEPT 50,ANS
50    FORMAT(A5)
      IF(ANS.EQ.'DEPRE') GO TO 100
      IF(ANS.EQ.'LIMIT') GO TO 400
      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.'SAVIN') 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
55    IMATCH=0
      CALL LOOK(IMATCH,ANS,LEVEL)
      IF(ANS.EQ.'STOP') RETURN 1
      IF(IMATCH.EQ.0) TYPE 60
60    FORMAT(' PLEASE CHECK THE NAME Y
                **OU ENTERED. IT IS
                **NOT',/
      1,' ON THE LIST. YOU MUST REENTE
                **R OR TYPE STOP.')
      GO TO 30
70    REREAD 80,ANS
      IMATCH=0
      CALL LOOK(IMATCH,ANS,LEVEL)
80    FORMAT(A5)
      IF(IMATCH.EQ.0) TYPE 90
90    FORMAT('  TYPE HELP FOR MORE INF
                **ORMATION')
      GO TO (400,430,480,520,550,650,6
                **90,630,670
```

```
      1,610,580,720,100,760) (LEVEL-2)
      TYPE 95,LEVEL
95    FORMAT(' THERE HAS BEEN AN ERROR
     **. LEVEL=',I2)
      RETURN 1
C
C     COMPUTE DEPRECIATION SCHEDULE
100   TYPE 110
110   FORMAT(' WHAT IS THE LIFETIME OF
     ** THE ASSET?',$)
      LEVEL=15
      READ(5,120,ERR=70) LIFE
120   FORMAT(I3)
      IF(LIFE.GE.1) GO TO 140
      TYPE 130
130   FORMAT(' THE LIFETIME MUST BE ON
     **E OR MORE. PLEASE
     **REENTER.')
      GO TO 100
140   TYPE 150
150   FORMAT(' WHICH METHOD OF DEPRECI
     **ATION DO YOU WANT
     **TO USE?',/
     1,T10,' STRAIGHT',T25,'-STRAIGHT
     ** LINE'
     2,/,T10,' DOUBLE',T25,'-DOUBLE D
     **ECLINING BALANCE'
     3,/,T10,' SUM',T25,'-SUM OF YEAR
     **S DIGITS',/,' METH
     **OD:',$)
      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 180 I=1,25
      SCHED(I)=1.0/FLOAT(LIFE)
      IF(I.GT.LIFE) SCHED(I)=0.0
180   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   METHOD=2
      PERC=2.0/FLOAT(LIFE)
      BALANC=1.0
      DO 220 I=1,24
      SCHED(I)=BALANC*PERC
220   BALANC=BALANC-SCHED(I)
      SCHED(25)=BALANC
      GO TO 300
C
C     SUM OF YEARS DIGITS METHOD
240   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
250   CONTINUE
      GO TO 300
C
C     SHOW SCHEDULE
300   SUM=0.0
      TYPE 310
310   FORMAT(' YEAR  FRACTION WRITTEN
     **OFF IN THAT YEAR')
      DO 330 I=1,25
      TYPE 320,I,SCHED(I)
320   FORMAT(2X,I2,5X,F5.3)
330   SUM=SUM+SCHED(I)
      TYPE 340,SUM
340   FORMAT(/,' TOTAL=',F5.3,//)
      GO TO 30
C
C     CHANGE TIME HORIZON
400   TYPE 410
410   FORMAT(' FOR HOW MANY YEARS SHOU
     **LD THE CASH FLOWS'
     **,
     1' BE CALCULATED?',$)
      LEVEL=3
      READ (5,420,ERR=70) LIMIT
420   FORMAT(I3)
      IF(LIMIT.LT.1) GO TO 450
      IF(LIMIT.GT.26) GO TO 450
      GO TO 30
C
C     CHANGE THE YEAR FLEET BECOMES CO
     **MPATIBLE
430   TYPE 440
440   FORMAT(' HOW MANY YEARS DOES THE
     ** SYSTEM TAKE TO BE
     **COME'
     1,' COMPATIBLE?',$)
      LEVEL=4
      READ (5,420,ERR=70) ICOMP
      IF(ICOMP.LT.0) GO TO 470
      IF(ICOMP.GE.26) GO TO 470
      GO TO 30
450   TYPE 460
460   FORMAT(' YEAR MUST BE BETWEEN 0
     **AND 26, PLEASE REE
     **NTER.')
      GO TO 400
470   TYPE 460
      GO TO 430
C
C     NUMBER OF CARS IN THE SYSTEM
480   TYPE 490
490   FORMAT(' HOW MANY CARS ARE IN TH
     **E SYSTEM?',$)
      LEVEL=5
      READ (5,500,ERR=70) NCAR
```

```
500     FORMAT(E10.0)
        IF(NCAR.GT.0.0) GO TO 30
        TYPE 510
510     FORMAT(' THERE HAS TO BE MORE TH
               **AN ZERO CARS.')
        GO TO 480
C
C       ATTRITION RATE
520     TYPE 530
530     FORMAT(' WHAT FRACTION OF THE CA
               **RS HAVE TO BE'
        1,' REPLACED EACH YEAR?',$)
        LEVEL=6
        READ (5,500,ERR=70) ATTRAT
        IF(ATTRAT.GE.0.0.AND.ATTRAT.LE.1
               **.0) GO TO 30
        TYPE 540
540     FORMAT(' THE ATTRITION RATE MUST
               ** BE BETWEEN ZERO A
               **ND ONE.')
        GO TO 520
C
C       ORIGINAL COST AS FRACTION OF NEW
               ** COST
550     TYPE 560
560     FORMAT(' WHAT FRACTION OF RETROF
               **IT COST IS REQUIRE
               **D FOR',/
        1,' NEW PRODUCTION (PER CAR)?',$
               **)
        LEVEL=7
        READ (5,500,ERR=70) FRAC
        XFRAC=FRAC*100.0
        TYPE 570,XFRAC
570     FORMAT(' FRACTION=',F6.1,'%')
        TYPE 571
571     FORMAT(' IS THIS CORRECT?',$)
        ACCEPT 50,XFRAC
        IF(XFRAC.NE.'YES') GO TO 550
        GO TO 30
C
C       FRACTION DEDUCTIBLE FOR INVESTME
               **NT TAX CREDIT
580     TYPE 590
590     FORMAT(' WHAT FRACTION OF INVEST
               **MENTS ARE DEDUCTIB
               **LE FOR',/
        1,' INVESTMENT TAX CREDIT?',$)
        LEVEL=13
        READ (5,500,ERR=70) FRIDT
        IF(FRIDT.GE.0.0) GO TO 30
        TYPE 600
600     FORMAT(' FRACTION CANNOT BE LESS
               ** THAN ZERO.')
        GO TO 580
C
C       TAX RATE
610     TYPE 620
620     FORMAT(' WHAT IS THE TAX RATE FO
               **R THE RAILROAD IND
               **USTRY?',$)
        LEVEL=12
        READ (5,500,ERR=70) TAXRAT
        IF(TAXRAT.GT.1) TAXRAT=TAXRAT/10
               **0.
        GO TO 30
C
C       UNION PAYOFF RATE
630     TYPE 640
640     FORMAT(' WHAT FRACTION OF LABOR
               **SAVINGS ARE PAID'
        1,' TO THE UNION?',$)
        LEVEL=10
        READ (5,500,ERR=70) UPAYRT
        IF(UPAYRT.GT.1.) UPAYRT=UPAYRT/1
               **00.
        GO TO 30
C
C       SAVINGS SUBJECT TO UNION
650     TYPE 660
660     FORMAT(' WHAT IS THE LABOR SAVIN
               **GS PER YEAR THAT I
               **S',/
        1,' SUBJECT TO UNION PAYOUT?',$)
        LEVEL=8
        READ (5,500,ERR=70) LABORS
        GO TO 30
C
C       SAVINGS NOT SUBJECT TO UNION PAY
               **OFF
670     TYPE 680
680     FORMAT(' WHAT IS THE ANNUAL SAVI
               **NGS NOT SUBJECT TO
               **',/
        1,' UNION PAYOUT?',$)
        LEVEL=11
        READ (5,500,ERR=70) SNSUP
        GO TO 30
C
C       STOP PAYING OFF UNION
690     TYPE 700
700     FORMAT(' FOR HOW MANY YEARS WILL
               ** SAVINGS BE PAID T
               **O THE UNION?'
        1,$)
        LEVEL=9
        READ (5,420,ERR=70) PAYSTP
        I=LIMIT-ICOMP
        IF(PAYSTP.GE.0.0.AND.PAYSTP.LE.I
               **) GO TO 30
        TYPE 710,LIMIT
710     FORMAT(' THERE MUST BE BETWEEN Z
               **ERO AND ',I2,' YEA
               **RS.')
        GO TO 690
C
C       INFLATION RATES
720     TYPE 730
730     FORMAT(' WHAT IS THE INFLATION R
               **ATE FOR:',/
        1,' MATERIALS (IN PERCENT)?',$)
        LEVEL=14
        READ (5,500,ERR=70) MATINF
        MATINF=1+(MATINF/100.)
        TYPE 740
740     FORMAT('+LABOR (IN PERCENT)?',$)
        READ (5,500,ERR=70) LABINF
        LABINF=1.+(LABINF/100.)
        TYPE 750
750     FORMAT('+SAVINGS NOT SUBJECT TO
               **UNION PAYOUT'
        1,' (IN PERCENT)?',$)
        READ (5,500,ERR=70) OINF
        OINF=1.+(OINF/100.)
        GO TO 30
C
C       RANGE OF DISCOUNT RATES TO BE US
               **ED
760     TYPE 770
770     FORMAT(' WHAT IS THE MINIMUM DIS
               **COUNT RATE (IN PER
               **CENT)?',$)
```

```
      LEVEL=16
      READ (5,420,ERR=70) LOW
      TYPE 780
780   FORMAT(' WHAT IS THE MAXIMUM DIS
     **COUNT RATE (IN PER
     **CENT)?',$)
      READ (5,420,ERR=70) HIGH
790   I=HIGH-LOW
      IF(I.EQ.0) GO TO 800
      IF(I.GT.0.AND.I.LT.25) GO TO 30
      IF(I.GE.25) GO TO 820
      I=HIGH
      HIGH=LOW
      LOW=I
      GO TO 790
800   TYPE 810
810   FORMAT(' PLEASE SPECIFY A WIDER
     **RANGE.')
      GO TO 760
820   TYPE 830
830   FORMAT(' PLEASE SPECIFY A NARROW
     **ER RANGE (LESS THA
     **N'
     1,' 25 PERCENTAGE POINTS).')
      GO TO 760
C
C     LABELS ON AXES
840   TYPE 850
850   FORMAT(' WHAT IS THE NEW LABEL F
     **OR THE X-AXIS?',/
     1,' MAXIMUM 10 CHARACTERS:',$)
      ACCEPT 860,XLABEL(1),XLABEL(2)
860   FORMAT(2A5)
      TYPE 870
870   FORMAT(' WHAT IS THE NEW LABEL F
     **OR THE Y-AXIS?',/
     1,' USE ; INSTEAD OF A CARRAIGE
     **RETURN.'
     1,' MAXIMUM 40 CHARACTERS:',$)
      ACCEPT 861,(YLABEL(I),I=1,40)
861   FORMAT(40A1)
      TYPE 880,XLABEL(1),XLABEL(2),(YL
     **ABEL(I),I=1,40)
880   FORMAT(' THE NEW LABELS ARE',/,'
     ** X-AXIS: ',2A5
     1,5X,' Y-AXIS: ',40A1,/,' ARE TH
     **ESE CORRECT?',$)
      ACCEPT 50,ANS
      IF(ANS.NE.'YES') GO TO 840
      GO TO 30
      END
C
C
C
C
      SUBROUTINE CRE($,MATCH)
C     GENERATE A LINE OF DATA
      DIMENSION X(26,2)
      COMMON LINES,DATA(26,2,10),POINT
     **(10),LABEL(10,2),W
     **IDTH(2)
     1,YLABEL(40),XLABEL(2)
      INTEGER POINT
      MATCH=1
      TYPE 10
10    FORMAT(' TYPE STOP TO TERMINATE
     **ENTRY',/
     1,' TYPE ERROR TO REENTER A NUMB
     **ER',/)
      I=0
20    I=I+1
25    IF(I.LT.10) TYPE 30,I
      IF(I.GE.10) TYPE 40,I
30    FORMAT('+X',I1,':'$)
40    FORMAT('+X',I2,':',$)
      READ (5,50,ERR=100),X(I,1)
50    FORMAT(F10.0)
      IF(I.LT.10) TYPE 60,I
      IF(I.GE.10) TYPE 70,I
60    FORMAT('+Y',I1,':',$)
70    FORMAT('+Y',I2,':',$)
      READ (5,50,ERR=100),X(I,2)
      TYPE 80,X(I,1),X(I,2)
80    FORMAT('+X=',F10.3,2X,'Y=',F10.3
     **,//)
      IF(I.LT.26) GO TO 20
      TYPE 90
90    FORMAT(' DATA VECTOR IS FULL',/
     1,' NO MORE POINTS CAN BE PLOTTE
     **D ON THIS LINE')
      GO TO 190
100   REREAD 110,ANS
110   FORMAT(A5)
      I=I-1
      IF(ANS.EQ.'STOP') GO TO 190
      CALL LOOK(IMATCH,ANS,LEVEL)
C     ASSUME ERROR NEEDS TO BE CORRECT
     **ED
115   TYPE 120
120   FORMAT(' TYPE STOP TO TERMINATE
     **ENTRY',/
     1,' X TO CORRECT AN X VALUE',/
     1,' Y TO CORRECT A Y VALUE',/
     3,' R TO RESUME NORMAL ENTRY')
125   TYPE 130
130   FORMAT(' X,Y,R OR STOP:',$)
      ACCEPT 110,ANS
      J=0
      IF(ANS.EQ.'R') GO TO 20
      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
135   TYPE 140,ANS
140   FORMAT(' WHICH ',A1,' DO YOU WAN
     **T TO CORRECT?',$)
      READ (5,150,ERR=115) K
150   FORMAT(I2)
      IF(K.LE.0) GO TO 170
      IF(K.GT.I+1) GO TO 170
      IF(K.EQ.I+1) GO TO 25
      TYPE 160,ANS,K
160   FORMAT(1X,A1,I2,'=',$)
      READ (5,50,ERR=115) X(K,J)
      GO TO 125
170   TYPE 180,I
180   FORMAT(' MUST BE BETWEEN 1 AND '
     **,I2,', PLEASE REEN
     **TER')
      GO TO 135
C     CLOSE ENTRY
190   TYPE 200
200   FORMAT(10X,'X',10X,'Y')
      DO 210 K=1,I
210   TYPE 220,K,X(K,1),X(K,2)
220   FORMAT(1X,I2,F10.3,5X,F10.3)
230   TYPE 240
240   FORMAT(' IS THIS CORRECT (YES OR
     ** NO)?',$)
      ACCEPT 110,ANS
      IF(ANS.EQ.'NO') GO TO 115
      IF(ANS.NE.'YES') GO TO 230
```

```
C       FILE DATA
        LINES=LINES+1
        POINT(LINES)=I
        DO 25Ø J=1,2
        DO 25Ø M=1,I
25Ø     DATA(M,J,LINES)=X(M,J)
        CALL LABL($26Ø,IMATCH)
26Ø     RETURN 1
        END
C
C
C
C       PROVIDE INITIAL VALUES FOR PARAM
                **ETERS
        BLOCK DATA
        COMMON LINES,DATA(26,2,1Ø),POINT
                **(1Ø),LABEL(1Ø,2),W
                **IDTH(2)
        1,YLABEL(4Ø),XLABEL(2),LIMIT,ICO
                **MP,X,NCAR,ATTRAT,M
                **ATINF
        2,LABINF,LABORS,LOW,HIGH,PAYSTP,
                **FRAC,FRIDT,TAXRAT,
                **UPAYRT
        3,SCHED(25),SNSUP,OINF,METHOD,LI
                **FE
        REAL NCAR,MATINF,LABINF,LABORS
        INTEGER POINT,YEAR,HIGH,LOW,PAYS
                **TP
        DATA LINES/Ø/
        DATA DATA/52Ø*Ø.Ø/
        DATA POINT/1Ø*Ø/
        DATA LABEL/2Ø*'     '/
        DATA WIDTH/5.5,9./
        DATA YLABEL/'D','D','L','L','A',
                **'R','S',';','A','V
                **','A','I','L'
        1,'A','B','L','E',' ','P','E','R
                **',';','F','R','E',
                **'I','G','H',
        2'T',' ','C','A','R',7*' '/
        DATA XLABEL/'DISCO','UNT %'/
        DATA LIMIT/21/
        DATA ICOMP/5/
        DATA NCAR/1.7EØ6/
        DATA ATTRAT/Ø.Ø37/
        DATA MATINF/1.1/
        DATA LABINF/1.Ø87/
        DATA LABORS/22ØEØ6/
        DATA LOW/5/
        DATA HIGH/25/
        DATA PAYSTP/1Ø/
        DATA FRAC/Ø.5/
        DATA FRIDT/Ø.1/
        DATA TAXRAT/Ø.46/
        DATA UPAYRT/.25/
        DATA SNSUP/Ø.Ø/
        DATA OINF/1.1/
        DATA METHOD/3/
        DATA LIFE/16/
        DATA SCHED/.118,.11Ø,.1Ø3,.Ø96,.
                **Ø88,.Ø81,.Ø74,.Ø66
        1,.Ø59,.Ø51,.Ø44,.Ø37,.Ø29,.Ø22,
                **.Ø15,.ØØ7,9*Ø.Ø/
        END
C
C
C
C       DELETE A LINE FROM DATA AND COMP
                **RESS
        SUBROUTINE DELET($,MATCH)
        COMMON LINES,DATA(26,2,1Ø),POINT
                **(1Ø),LABEL(1Ø,2)
        INTEGER POINT
        MATCH=1
1       IF(LINES.GT.Ø) GO TO 5
        TYPE 2
2       FORMAT(' THERE ARE NO MORE LINES
                ** TO DELETE.')
        RETURN 1
5       TYPE 1Ø,LINES
1Ø      FORMAT(' THERE ARE NOW ',I2,' LI
                **NES. WHICH ONE DO
                **YOU',/
        1,' WANT TO DELETE? TYPE PRINT T
                **O SEE THE REMAININ
                **G DATA.',/
        2,' TYPE STOP WHEN FINISHED.',/
        3,' LINE:',$)
        LEVEL=19
        READ (5,2Ø,ERR=45) LINE
2Ø      FORMAT(I3)
        IF(LINE.LT.1) GO TO 3Ø
        IF(LINE.GT.LINES) GO TO 3Ø
        IF(LINE.NE.LINES) GO TO 6Ø
        LINES=LINES-1
        GO TO 1
C
C       ERROR MESSAGE
3Ø      TYPE 4Ø,LINES
4Ø      FORMAT(' LINE NUMBER MUST BE BET
                **WEEN 1 AND ',I2,/
        2,' PLEASE REENTER OR TYPE STOP.
                **')
        GO TO 1
45      REREAD 5Ø,ANS
5Ø      FORMAT(A5)
        IF(ANS.EQ.'STOP') RETURN 1
        CALL LOOK(IMATCH,ANS,LEVEL)
        GO TO 1
C
C       COMPRESS DATA
6Ø      DO 9Ø I=LINE,LINES-1
        J=I+1
        ENCODE(5,7Ø,LABEL(I,1)) LABEL(J,
                **1)
        ENCODE(5,7Ø,LABEL(I,2)) LABEL(J,
                **2)
7Ø      FORMAT(A5)
        DO 8Ø K=1,POINT(J)
        DATA(K,1,I)=DATA(K,1,J)
        DATA(K,2,I)=DATA(K,2,J)
8Ø      CONTINUE
9Ø      POINT(I)=POINT(J)
        LINES=LINES-1
        GO TO 1
        END
C
C
C
C
        SUBROUTINE GRA($,MATCH)
C
C       PLOT AXES, PLOT EACH LINE IN THE
                ** MATRIX
```

```
C         DATA, LABEL EACH LINE, PLACE TIT
                    **LE UNDER GRAPH
          DIMENSION MIN(2),MAX(2),DIFF(2),
                    **TITLE(50),ISORT(10
                    **),
          1MAG(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)
          1,YLABEL(40),XLABEL(2)
          INTEGER POINT,IEND(10)
          REAL MIN,MAX,MAG
          DATA TITLEX/4.0/
          DATA TITLEY/9.00/
          DATA TITLE/50*' '/
          MATCH=1
C
C         DETERMINE IF THERE IS PLOTTING T
                    **O BE DONE
          IF(LINES.LT.1) GO TO 170
C
C         FIND MINIMUM AND MAXIMUM VALUES
                    **FOR EACH AXIS
          DO 50 J=1,2
          MAX(J)=DATA(1,J,1)
          MIN(J)=DATA(1,J,1)
          DO 10 K=1,LINES
          DO 10 I=1,POINT(K)
          IF(MIN(J).GT.DATA(I,J,K)) MIN(J)
                    **=DATA(I,J,K)
10        IF(MAX(J).LT.DATA(I,J,K)) MAX(J)
                    **=DATA(I,J,K)
C
C         FIND RANGE FOR EACH AXIS AND CHO
                    **OSE UPPER AND LOWE
                    **R
C         BOUNDS SO THAT BOUNDARIES WILL B
                    **E ROUND NUMBERS
          DIFF(J)=MAX(J)-MIN(J)
          A=DIFF(J)
          IF(A.EQ.0.0) GO TO 170
          IEXP=0
          PTEN=1.0
11        IF(A.GE.1.0) GO TO 12
          A=A*10.0
          IEXP=IEXP-1
          PTEN=PTEN/10.0
          GO TO 11
12        IF(A.LT.10.0) GO TO 13
          A=A/10.0
          IEXP=IEXP+1
          PTEN=PTEN*10
          GO TO 12
13        MAG(J)=AINT(A)
C
C         XINC IS THE INTERVAL BETWEEN SLA
                    **SHES 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.0.0) MIX=MIX-1
          IF(MAX(J).GT.0.0) MAN=MAN+1
C
C         CHOOSE UPPER BOUND AS THE LOWEST
                    ** ROUND NUMBER ABOV
                    **E
C         THE MAXIMUM VALUE TO BE PLOTTED
          MAX(J)=XINC(J)*MAN
          MIN(J)=XINC(J)*MIX
C
C         ITICK IS THE NUMBER OF SLAHES TO
                    ** BE DRAWN ON THE A
                    **XIS
          ITICK(J)=1+MAN-MIX
          DIFF(J)=MAX(J)-MIN(J)
C
C         IDEC IS THE NUMBER OF FIGURES TO
                    ** THE RIGHT OF THE
                    **DECIMAL
C         POINT TO BE WRITTEN NEXT TO THE
                    **TICKS ON THE AXES
          IDEC(J)=0-IEXP
C
C         ISIG IS THE NUMBER OF DIGITS PLO
                    **TTED NEXT TO THE T
                    **ICKS
          X=AMAX1(ABS(MIN(J)),ABS(MAX(J)))
          ISIG(J)=2+MAX0(0,INT(ALOG10(X)))
                    **+MAX0(0,IDEC(J))
C
C         COMPUTE SCALE FACTOR BASED ON TH
                    **E GRAPH DIMENSIONS
          IF(WIDTH(J).LT.1.0) GO TO 190
45        SCALE(J)=DIFF(J)/WIDTH(J)
50        CONTINUE
C
C         FIND TITLE FOR GRAPH
51        TYPE 52
52        FORMAT(' DO YOU WANT A TITLE ON
                    **THIS GRAPH?',$)
          LEVEL=20
          ACCEPT 55,ANS
55        FORMAT(A5)
          IF(ANS.EQ.'NO') GO TO 54
          IF(ANS.EQ.'YES') GO TO 345
          CALL LOOK(IMATCH,ANS,LEVEL)
          GO TO 51
300       TYPE 310
310       FORMAT(' HOW FAR ABOVE THE X-AXI
                    **S DO YOU WANT THE'
                    **/
          1,' TOP OF THE FIRST LINE TO BE
                    **(IN INCHES,BETWEEN
                    ** -1 AND 10)?'
          2,$)
          READ (5,330,ERR=400) TITLEY
330       FORMAT(E10.0)
          TYPE 340
340       FORMAT(' HOW FAR TO THE RIGHT OF
                    ** THE Y-AXIS DO YOU
                    ** WANT'
          1,/,' THE LEFT HAND EDGE OF THE
                    **TITLE (BETWEEN 0 A
                    **ND 6)?',$)
          READ (5,330,ERR=400) TITLEX
345       TYPE 350,TITLEY,TITLEX
350       FORMAT(' THE TITLE WILL BE ',F4.
                    **1,' INCHES ABOVE T
                    **HE X-AXIS',/
          1,' AND ',F4.1,' INCHES TO THE R
                    **IGHT OF THE Y-AXIS
                    **.',/
```

```
      2,' IS THIS CORRECT?',$)
      ACCEPT 55,ANS
      IF(ANS.NE.'YES') GO TO 300
355   TYPE 360
360   FORMAT(' WHAT IS THE TITLE? USE
                **; INSTEAD OF CARRA
                **IGE RETURN.'/
      1,' MAXIMUM 50 CHARACTERS:',$)
      ACCEPT 370,(TITLE(I),I=1,50)
370   FORMAT(50A1)
      TYPE 380,(TITLE(I),I=1,50)
380   FORMAT(' IS THIS CORRECT: ',50A1
                **,/,' (YES OR NO):'
                **,$)
      ACCEPT 55,ANS
      IF(ANS.NE.'YES') GO TO 355
      GO TO 54
400   REREAD 55,ANS
      CALL LOOK(IMATCH,ANS,LEVEL)
      GO TO 300
C
C     MOVE PAPER AND CHOOSE ORIGIN
54    CALL PLOT(0.0,0.0,-3)
      CALL PLOT(3.0,0.0,-2)
      CALL PLOT(10.0,-12.0,-3)
      CALL PLOT(0.0,1.0,-1)
C
C     DRAW X-AXIS
      X=WIDTH(1)
      CALL PLOT(X,0.0,2)
C
C     LABEL THE X-AXIS
      X=WIDTH(1)+.3
      DO 56 J=1,2
      IF(XLABEL(J).EQ.'      ') GO TO 5
                **7
      CALL SYMBOL(X,-0.25,.15,XLABEL(J
                **),0.0,5)
      X=X+.75
56    CONTINUE
C
C     DRAW TICKS ON THE X-AXIS
57    DO 60 I=ITICK(1),1,-1
      XPOINT=MIN(1)+XINC(1)*(I-1)
      XLOC=XINC(1)*(I-1)/SCALE(1)
      CALL PLOT(XLOC,0.0,3)
      CALL PLOT(XLOC,-.1,2)
      X=XLOC-(ISIG(1)*0.075)
      CALL NUMBER(X,-.25,.15,XPOINT,0.
                **0,IDEC(1))
60    CONTINUE
C
C     DRAW Y-AXIS
      Y=WIDTH(2)
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,Y,2)
C
C     LABEL THE Y-AXIS
      Y=WIDTH(2)+0.3
      X=.1
      DO 64 I=1,40
      IF(YLABEL(I).NE.';') GO TO 61
      Y=Y-.2
      X=.1
      GO TO 64
61    CALL SYMBOL(X,Y,0.15,YLABEL(I),0
                **.0,1)
      X=X+0.15
64    CONTINUE
C
C     DRAW TICKS ON THE Y-AXIS
65    DO 70 I=ITICK(2),1,-1
      YPOINT=MIN(2)+XINC(2)*(I-1)
      YLOC=XINC(2)*(I-1)/SCALE(2)
      CALL PLOT(0.0,YLOC,3)
      CALL PLOT(-.1,YLOC,2)
      Y=YLOC-.05
      X=ISIG(2)*-0.15-0.1
      CALL NUMBER(X,Y,.15,YPOINT,0.0,I
                **DEC(2))
70    CONTINUE
C
C     CALCULATE BASELINE; POINT WHERE
                **(0,0) WOULD PLOT
      XZERO=MIN(1)/SCALE(1)
      YZERO=MIN(2)/SCALE(2)
C
C     MOVE PEN TO START OF LINE
      DO 90 LINE=1,LINES
      X=DATA(1,1,LINE)/SCALE(1)-XZERO
      Y=DATA(1,2,LINE)/SCALE(2)-YZERO
      CALL PLOT(X,Y,3)
      IF(POINT(LINE).LE.1) GO TO 80
C
C     DRAW A LINE
      DO 80 I=2,POINT(LINE)
      X=DATA(I,1,LINE)/SCALE(1)-XZERO
      Y=DATA(I,2,LINE)/SCALE(2)-YZERO
      CALL PLOT(X,Y,2)
80    CONTINUE
90    CONTINUE
C
C     PUT LABEL TO THE RIGHT OF EACH L
                **INE
C
C     FIND ENDPOINTS OF LINES
      IF(LINES.EQ.1) GO TO 140
      DO 100 LINE=1,LINES
      IEND(LINE)=1
      ISORT(LINE)=LINE
      IF(POINT(LINE).LT.2) GO TO 135
      DO 100 IBUBLE=2,POINT(LINE)
      IF(DATA(IBUBLE,1,LINE).GT.DATA(I
                **END(LINE),1,LINE))
      1 IEND(LINE)=IBUBLE
100   CONTINUE
C
C     SORT ENDPOINTS OF LINES SO LABEL
                **S WILL APPEAR IN T
                **HE RIGHT ORDER
110   IBUBLE=0
      IDONE=1
120   IBUBLE=IBUBLE+1
      JBUBLE=IBUBLE+1
      ILINE=ISORT(IBUBLE)
      JLINE=ISORT(JBUBLE)
      YI=DATA(IEND(ILINE),2,ILINE)
      YJ=DATA(IEND(JLINE),2,JLINE)
      IF(YI.LE.YJ) GO TO 130
C
C     SWITCH POINTERS (USE JPOINT AS T
                **EMPORARY STORAGE)
      JPOINT=ISORT(IBUBLE)
      ISORT(IBUBLE)=ISORT(JBUBLE)
      ISORT(JBUBLE)=JPOINT
      IDONE=0
130   IF(JBUBLE.LT.LINES) GO TO 120
C
```

```
C          IF STILL OUT OF ORDER RETURN FOR
                   ** ANOTHER PASS
           IF(IDONE.EQ.Ø) GO TO 11Ø
135        X=WIDTH(1)+.75
           YJ=Ø.Ø
           DO 15Ø IBUBLE=1,LINES
           LINE=ISORT(IBUBLE)
           Y=DATA(IEND(LINE),2,LINE)/SCALE(
                   **2)-YZERO-Ø.1
C
C          CHECK FOR OVERWRITE
           IF(IBUBLE.EQ.1) GO TO 14Ø
           JBUBLE=IBUBLE-1
           JLINE=ISORT(JBUBLE)
C
C          MOVE LABEL UP IF IT WILL OVERWRI
                   **TE PREVIOUS LABEL
           YJ=Y-YJ
           IF(YJ.GT.Ø.2) GO TO 14Ø
           Y=Y+Ø.2-YJ
C
C          PUT LABEL NEXT TO ENDPOINT
14Ø        IF(LABEL(LINE,1).EQ.'      ') GO
                   **TO 145
           CALL SYMBOL(WIDTH(1),Y,Ø.15,LABE
                   **L(LINE,1),Ø.Ø,5)
           IF(LABEL(LINE,2).EQ.'      ') GO
                   **TO 145
           CALL SYMBOL(X,Y,Ø.15,LABEL(LINE,
                   **2),Ø.Ø,5)
145        YJ=Y
15Ø        CONTINUE
C
C          PUT TITLE UNDER GRAPH
           Y=TITLEY-Ø.2
           X=TITLEX
           DO 155 I=1,5Ø
           IF(TITLE(I).NE.';') GO TO 152
           X=TITLEX
           Y=Y-Ø.25
           GO TO 155
152        CALL SYMBOL(X,Y,Ø.2,TITLE(I),Ø.Ø
                   **,1)
           X=X+Ø.2
155        CONTINUE
16Ø        TYPE 161
161        FORMAT(' TYPE YES IF YOU ARE FIN
                   **ISHED WITH THE',/
           1,' DATA JUST GRAPHED. TYPE NO I
                   **F YOU WISH TO',/
           2,' USE IT AGAIN. CLEAR DATA?',$
                   **)
           ACCEPT 162,ANS
162        FORMAT(A3)
           IF(ANS.EQ.'NO') GO TO 165
           IF(ANS.NE.'YES') GO TO 16Ø
           LINES=Ø
165        RETURN 1
17Ø        TYPE 18Ø
18Ø        FORMAT(' THERE ARE NO LINES TO P
                   **LOT')
           RETURN 1
19Ø        TYPE 2ØØ
2ØØ        FORMAT(' WIDTH IS TOO SMALL. PLE
                   **ASE CORRECT')
           RETURN 1
           END
```

```
C
C
C          PROVIDE USER INSTRUCTIONS AT VAR
                   **IOUS POINTS OF THE
                   ** PROGRAM
           SUBROUTINE HELP($,MATCH,LEVEL)
           MATCH=1
           GO TO (2Ø,4Ø,8Ø,1ØØ,11Ø,12Ø,13Ø,
                   **14Ø,15Ø,16Ø,17Ø,18
                   **Ø,19Ø
           1,2ØØ,6Ø,21Ø,23Ø,25Ø,27Ø,29Ø) LE
                   **VEL
C
C          IF LEVEL = Ø, NO MORE INFORMATIO
                   **N IS AVAILABLE
           TYPE 1Ø
1Ø         FORMAT(' THERE IS NO MORE INFORM
                   **ATION AVAILABLE'
           1,' FOR THIS SECTION.' )
           RETURN 1
C
C          MODEL HAS NOT YET BEEN CALLED
2Ø         TYPE 3Ø
3Ø         FORMAT(' THIS PROGRAM CONTAINS A
                   ** NUMBER OF SUBPROG
                   **RAMS'
           1,' TO PERFORM SPECIFIC TASKS.',
                   **/,' TO USE ONE '
           2,'TYPE THE KEYWORD FOR THAT UNI
                   **T.'
           3,//,' KEYWORD',T2Ø,'FUNCTION'
           4,/,'  HELP',T14,'INFORMATION AB
                   **OUT A PARTICULAR Q
                   **UESTION'
           5,/,'  MODEL',T14,'SET PARAMETER
                   **S FOR BRAKING'
           5,' AND COUPLING MODEL'
           6,/,'  CHANGE',T14,'CHANGE SPECI
                   **FIC PARAMETERS IN
                   **THE MODEL'
           7,/,'  SOLVE',T14,'SOLVE FOR AVA
                   **ILABLE DOLLARS PER
                   ** CAR'
           8,' AND STORE THE RESULTS'
           8,/,'  VARIABLE',T14,'SOLVE FOR
                   **DOLLARS PER CAR WI
                   **TH'
           8,' VARIABLE SAVINGS OVER TIME'
           9,/,'  GRAPH',T14,'PLOT THE DATA
                   ** IN THE FILE'
           1,/,'  PRINT',T14,'PRINT THE DAT
                   **A IN THE FILE'
           2,/,'  LIST',T14,'THE PARAMETERS
                   ** AND THEIR VALUES
                   **IN THE MODEL'
           3,/,'  DELETE',T14,'REMOVE ONE O
                   **R MORE LINES FROM
                   **THE DATA FILE'
           4,/,'  CREATE',T14,'ENTER A LINE
                   ** INTO THE FILE',//
                   **)
           TYPE 35
35         FORMAT(/,' THIS PROGRAM WILL NOW
                   ** AUTOMATICALLY ENT
                   **ER MODEL'
           6,' AND THEN LIST.',/,' YOU CAN
                   **THEN USE CHANGE TO
                   ** CORRECT',
           7' ANY ERRORS. THEN TYPE SOLVE F
                   **OLLOWED',/,' BY PR
                   **INT OR GRAPH.'
```

```
        8,/,' NOTE THAT PRINT AND GRAPH
                **WILL OUTPUT ALL TH
                **E SOLUTIONS'
        9,/,' MADE UP TO THAT TIME. PART
                **ICULAR SOLUTIONS C
                **AN BE REMOVED'
        1,' WITH DELETE.'//)
        CALL MODEL($36,IMATCH,LEVEL)
36      LEVEL=2
        RETURN 1
C
C       INSTRUCTION:HELP
40      TYPE 30
        TYPE 50
50      FORMAT(' IF THERE ARE ANY PARAME
                **TERS 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'
        6,' TO TEN LINES ON THE GRAPH.')
        LEVEL=0
        RETURN 1
C
C       LIFETIME OF THE ASSET (MODEL,CHA
                **NGE)
60      TYPE 70
70      FORMAT(' THE DEPRECIATION SCHEDU
                **LE IS BASED ON'
        1,' THE LIFETIME ASSIGNED TO THE
                ** ',/,' EQUIPMENT.'
        2,' YOUR ANSWER SHOULD BE AN INT
                **EGER BETWEEN 1 AND
                ** 99.')
        RETURN 1
C
C       TIME HORIZON
80      TYPE 90
90      FORMAT(' THE FIRST CASH FLOW WIL
                **L BE ASSUMED TO BE
                **'
        1,' IN YEAR ONE. YOUR',/,' RESPO
                **NSE SHOULD BE BETW
                **EEN 1 AND 26.'
        2,' CASH FLOWS OCCURING AFTER TH
                **IS '
        1,/,' LIMIT WILL BE IGNORED.')
        RETURN 1
C
C       COMPATIBLE
100     TYPE 10
        RETURN 1
110     TYPE 10
        RETURN 1
120     TYPE 10
        RETURN 1
130     TYPE 10
        RETURN 1
140     TYPE 10
        RETURN 1
150     TYPE 10
        RETURN 1
160     TYPE 10
        RETURN 1
170     TYPE 10
        RETURN 1
180     TYPE 10
        RETURN 1
190     TYPE 10
        RETURN 1
200     TYPE 10
        RETURN 1
210     TYPE 220
220     FORMAT(' THESE RATES REFER TO TH
                **E MAXIMUM AND MINI
                **MUM'
        1,' RATES TO BE USED IN',/,' PLO
                **TTING DOLLARS VERS
                **US'
        2,' DISCOUNT RATE.')
        RETURN 1
230     TYPE 240
240     FORMAT(' TYPE LIST FOR A LIST OF
                ** PARAMETERS. THEN'
        1,' TYPE THE KEYWORD OF THE',/,'
                ** PARAMETER YOU WIS
                **H'
        2,' TO CHANGE. WHEN YOU ARE FINI
                **SHED CHANGING, TYP
                **E STOP.')
        RETURN 1
250     TYPE 260
260     FORMAT(' AFTER X TYPE THE VALUE
                **YOU WISH TO REFER
                **TO THE'
        1,' X-COORDINATE OF A POINT',/,'
                ** ON THE LINE. NOTE
                ** THAT THE'
        2,' POINTS WILL BE CONNECTED IN
                **THE ORDER'
        1,/,' YOU ENTER THEM.')
        RETURN 1
270     TYPE 280
280     FORMAT(' ENTER THE LINE NUMBER (
                **AS LISTED AFTER TY
                **PING'
        1,' PRINT) CORRESPONDING TO',/,'
                ** THE LINE YOU WISH
                ** TO DELETE'
        2,'. TYPE STOP WHEN FINISHED.')
        RETURN 1
290     TYPE 300
300     FORMAT(' THE TITLE WILL APPEAR O
                **N THE GRAPH. YOU C
                **AN SELECT'
        1,' SELECT THE LOCATION',/,' REL
                **ATIVE TO THE AXES
                **AND'
        2,' MORE THAN ONE LINE MAY BE US
                **ED.')
        RETURN 1
        END
C
C
C
C       LABEL THE LAST LINE GENERATED
```

```
      SUBROUTINE LABL($,MATCH)
      COMMON LINES,DATA(26,2,10),POINT
     **(10),LABEL(10,2)
      INTEGER POINT
      MATCH=1
10    TYPE 20
20    FORMAT(' LABEL (MAXIMUM 10 CHARA
     **CTERS):',$)
      ACCEPT 30,LABEL(LINES,1),LABEL(L
     **INES,2)
30    FORMAT(2A5)
40    TYPE 50,LABEL(LINES,1),LABEL(LIN
     **ES,2)
50    FORMAT(1X,2A5,5X,'IS THE LABEL C
     **ORRECT?',$)
      ACCEPT 60,ANS
60    FORMAT(A5)
      IF(ANS.EQ.'NO') GO TO 10
      IF(ANS.NE.'YES') GO TO 40
      IF(LINES.NE.1) TYPE 70,LINES
70    FORMAT(' THERE ARE NOW ',I2,' LI
     **NES ON THE GRAPH.'
     **)
      IF(LINES.EQ.1) TYPE 80
80    FORMAT(' THERE IS NOW 1 LINE ON
     **THE GRAPH.')
      RETURN 1
      END
C
C
C
C     LIST THE PARAMETERS AND THE CURR
     **ENT VALUE OF EACH
      SUBROUTINE LIST($,MATCH)
      COMMON LINES,DATA(26,2,10),POINT
     **(10),LABEL(10,2),W
     **IDTH(2)
     1,YLABEL(40),XLABEL(2),LIMIT,ICO
     **MP,X,NCAR,ATTRAT,M
     **ATINF
     2,LABINF,LABORS,LOW,HIGH,PAYSTP,
     **FRAC,FRIDT,TAXRAT,
     **UPAYRT
     3,SCHED(25),SNSUP,OINF,METHOD,LI
     **FE
      REAL NCAR,MATINF,LABINF,LABORS
      INTEGER POINT,YEAR,HIGH,LOW,PAYS
     **TP
      MATCH=1
      TYPE 10
10    FORMAT(' VARIABLE',T37,'KEYWORD'
     **,T55,'CURRENT VALU
     **E')
      TYPE 20,LIMIT,ICOMP,NCAR,ATTRAT,
     **FRAC,FRIDT,TAXRAT
20    FORMAT(' NUMBER OF YEARS IN ANAL
     **YSIS',T38,'LIMIT',
     **T63,I2,/
     1,' YEARS BEFORE SYSTEM IS COMPA
     **TIBLE',T38,'COMPAT
     **IBLE',T63,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,'
     **FRACTION',T55,F14.
     **3,/
     5,' INVESTMENT TAX CREDIT',T38,'
     **INVESTMENT',T55,F1
     **4.3,/
     6,' TAX RATE',T38,'TAX',T55,F14.
     **3)
      TYPE 30,UPAYRT,LABORS,PAYSTP,SNS
     **UP,MATINF,LABINF,O
     **INF
30    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
     **ION',T38,'LOSE',T6
     **3,I2,/
     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
40    FORMAT(' MINIMUM DISCOUNT RATE',
     **T38,'RATES',T63,I2
     **,/
     1,' MAXIMUM DISCOUNT RATE',T38,'
     **RATES',T63,I2,/
     2,' DEPRECIATION',T38,'DEPRECIAT
     **ION',/
     3,T8,' LIFETIME OF ASSETS',T63,I
     **2,/,8X,$)
      IF(METHOD.EQ.1) TYPE 50
      IF(METHOD.EQ.2) TYPE 60
      IF(METHOD.EQ.3) TYPE 70
50    FORMAT(' STRAIGHT LINE',$)
60    FORMAT(' DOUBLE DECLINING BALANC
     **E',$)
70    FORMAT(' SUM OF YEARS DIGITS',$)
      TYPE 80
80    FORMAT('  DEPRECIATION USED.')
      TYPE 90,XLABEL(1),XLABEL(2),(YLA
     **BEL(I),I=1,40)
90    FORMAT(' THE AXES ARE LABELED AS
     ** FOLLOWS:',/
     1,' X-AXIS: ',2A5,5X,' Y-AXIS: '
     **,40A1,/,20X,'KEYWO
     **RD IS AXES')
      RETURN 1
      END
C
C
C
C     LOOK FOR COMMAND THAT MATCHES TH
     **E INPUT
      SUBROUTINE LOOK(IMATCH,ANS,LEVEL
     **)
      IF(ANS.EQ.'CREAT') CALL CRE($10,
     **IMATCH)
      IF(ANS.EQ.'GRAPH') CALL GRA($10,
     **IMATCH)
      IF(ANS.EQ.'CHANG') CALL CHANG($1
     **0,IMATCH)
      IF(ANS.EQ.'DELET') CALL DELET($1
     **0,IMATCH)
      IF(ANS.EQ.'PRINT') CALL PRINT($1
     **0,IMATCH)
      IF(ANS.EQ.'SOLVE') CALL SOLVE($1
     **0,IMATCH)
      IF(ANS.EQ.'SOLVE') CALL LABL($10
     **,IMATCH)
```

```
      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
                 **0,IMATCH,LEVEL)
      IF(ANS.EQ.'VARIA') CALL VARIA($1
                 **0,IMATCH)
      IF(ANS.EQ.'VARIA') CALL LABL($10
                 **,IMATCH)
      RETURN
10    ANS='NULL'
      IMATCH=1
      RETURN
      END
C
C
C
C     CONSTRUCT A SET OF PARAMETERS FR
                 **OM SCRATCH
      SUBROUTINE MODEL($,MATCH,LEVEL)
      COMMON LINES,DATA(26,2,10),POINT
                 **(10),LABEL(10,2),W
                 **IDTH(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,DINF,METHOD,LIF
                 **E
      REAL NCAR,MATINF,LABINF,LABORS
      INTEGER POINT,YEAR,HIGH,LOW,PAYS
                 **TP
      MATCH=1
C
C     TYPE HEADING
      TYPE 1
1     FORMAT(' THIS IS A MODEL TO ESTI
                 **MATE THE AMOUNT TH
                 **AT CAN',/
     1,' BE SPENT PER FREIGHT CAR FOR
                 ** ADVANCED BRAKING'
                 **,/
     2,' AND COUPLING.')
      GO TO 21
C
C     ERROR PROCEDURE
10.   REREAD 12,ANS
      IMATCH=0
      CALL LOOK(IMATCH,ANS,LEVEL)
12    FORMAT(A5)
      IF(IMATCH.EQ.0) TYPE 11
11    FORMAT(' PLEASE USE ONLY 1 TO 9,
                 **0,+,-,. IN YOUR RE
                 **SPONSE.',/
     1,' TYPE HELP FOR MORE INFORMATI
                 **ON.')
      GO TO (21,21,21,21,22,23,24,25,2
                 **6,27,28,29,30,31,3
                 **2,33)
     1,(LEVEL+1)
      TYPE 5,LEVEL
5     FORMAT(' THERE HAS BEEN AN ERROR
                 **. LEVEL=',I2)
      RETURN 1
C
C     GO TO THE NEXT QUESTION
21    GO TO 400
22    GO TO 430
23    GO TO 480
24    GO TO 520
25    GO TO 550
26    GO TO 650
27    GO TO 690
28    GO TO 630
29    GO TO 670
30    GO TO 610
31    GO TO 580
32    GO TO 720
33    GO TO 100
34    CALL LIST($35,IMATCH)
35    RETURN 1
C
C     COMPUTE DEPRECIATION SCHEDULE
100   TYPE 110
110   FORMAT(' WHAT IS THE LIFETIME OF
                 ** THE ASSET?',$)
      LEVEL=15
      READ(5,120,ERR=10) LIFE
120   FORMAT(I3)
      IF(LIFE.GE.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,T10,' STRAIGHT',T25,'-STRAIGHT
                 ** LINE'
     2,/,T10,' DOUBLE',T25,'-DOUBLE D
                 **ECLINING BALANCE'
     3,/,T10,' SUM',T25,'-SUM OF YEAR
                 **S DIGITS',/,' METH
                 **OD:',$)
      ACCEPT 151,ANS
151   FORMAT(A5)
      IF(ANS.EQ.'STRAI') GO TO 170
      IF(ANS.EQ.'DOUBL') GO TO 190
      IF(ANS.EQ.'SUM') GO TO 240
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
C
C     STRAIGHT LINE METHOD
170   METHOD=1
      DO 180 I=1,25
      SCHED(I)=1.0/FLOAT(LIFE)
      IF(I.GT.LIFE) SCHED(I)=0.0
```

```
180     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     METHOD=2
        PERC=2.0/FLOAT(LIFE)
        BALANC=1.0
        DO 220 I=1,24
        SCHED(I)=BALANC*PERC
220     BALANC=BALANC-SCHED(I)
        SCHED(25)=BALANC
        GO TO 300
C
C       SUM OF YEARS DIGITS METHOD
240     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
250     CONTINUE
        GO TO 300
C
C       SHOW SCHEDULE
300     SUM=0.0
        TYPE 310
310     FORMAT(' YEAR  FRACTION WRITTEN
                **OFF IN THAT YEAR')
        DO 330 I=1,25
        TYPE 320,I,SCHED(I)
320     FORMAT(2X,I2,5X,F5.3)
330     SUM=SUM+SCHED(I)
        TYPE 340,SUM
340     FORMAT(/,' TOTAL=',F5.3,//)
        GO TO 34
C
C       CHANGE TIME HORIZON
400     TYPE 410
410     FORMAT(' FOR HOW MANY YEARS SHOU
                **LD THE CASH FLOWS'
                **,
        1' BE CALCULATED?',$)
        LEVEL=3
        READ (5,420,ERR=10) LIMIT
420     FORMAT(I3)
        IF(LIMIT.LT.1) GO TO 450
        IF(LIMIT.GT.26) GO TO 450
        GO TO 22
C
C       CHANGE THE YEAR FLEET BECOMES CO
                **MPATIBLE
430     TYPE 440
440     FORMAT(' HOW MANY YEARS DOES THE
                ** SYSTEM TAKE TO BE
                **COME'
        1,' COMPATIBLE?',$)
        LEVEL=4
        READ (5,420,ERR=10) ICOMP
        IF(ICOMP.LT.0) GO TO 470
        IF(ICOMP.GE.26) GO TO 470
        GO TO 23
450     TYPE 460
460     FORMAT(' YEAR MUST BE BETWEEN 0
                **AND 26, PLEASE REE
                **NTER.')
        GO TO 400
470     TYPE 460
        GO TO 430
C
C       NUMBER OF CARS IN THE SYSTEM
480     TYPE 490
490     FORMAT(' HOW MANY CARS ARE IN TH
                **E SYSTEM?',$)
        LEVEL=5
        READ (5,500,ERR=10) NCAR
500     FORMAT(E10.0)
        IF(NCAR.GT.0.0) GO TO 24
        TYPE 510
510     FORMAT(' THERE HAS TO BE MORE TH
                **AN ZERO CARS.')
        GO TO 480
C
C       ATTRITION RATE
520     TYPE 530
530     FORMAT(' WHAT FRACTION OF THE CA
                **RS HAVE TO BE'
        1,' REPLACED EACH YEAR?',$)
        LEVEL=6
        READ (5,500,ERR=10) ATTRAT
        IF(ATTRAT.GE.0.0.AND.ATTRAT.LE.1
                **.0) GO TO 25
        TYPE 540
540     FORMAT(' THE ATTRITION RATE MUST
                ** BE BETWEEN ZERO A
                **ND ONE.')
        GO TO 520
C
C       ORIGINAL COST AS FRACTION OF NEW
                ** COST
550     TYPE 560
560     FORMAT(' WHAT FRACTION OF RETROF
                **IT COST IS REQUIRE
                **D FOR',/
        1,' NEW PRODUCTION (PER CAR)?',$
                **)
        LEVEL=7
        READ (5,500,ERR=10) FRAC
        XFRAC=FRAC*100.0
        TYPE 570,XFRAC
570     FORMAT(' FRACTION=',F6.1,'%')
        TYPE 571
571     FORMAT(' IS THIS CORRECT?',$)
        ACCEPT 151,XFRAC
        IF(XFRAC.NE.'YES') GO TO 550
        GO TO 26
C
C       FRACTION DEDUCTIBLE FOR INVESTME
                **NT TAX CREDIT
580     TYPE 590
590     FORMAT(' WHAT FRACTION OF INVEST
                **MENTS ARE DEDUCTIB
                **LE FOR',/
        1,' INVESTMENT TAX CREDIT?',$)
        LEVEL=13
        READ (5,500,ERR=10) FRIDT
        IF(FRIDT.GE.0.0) GO TO 32
        TYPE 600
600     FORMAT(' FRACTION CANNOT BE LESS
                ** THAN ZERO.')
        GO TO 580
C
C       TAX RATE
610     TYPE 620
```

```
620     FORMAT(' WHAT IS THE TAX RATE FO
                **R THE RAILROAD IND
                **USTRY?',$)
        LEVEL=12
        READ (5,500,ERR=10) TAXRAT
        IF(TAXRAT.GT.1) TAXRAT=TAXRAT/10
                **0.
        GO TO 31
C
C       UNION PAYOFF RATE
630     TYPE 640
640     FORMAT(' WHAT FRACTION OF LABOR
                **SAVINGS ARE PAID'
        1,' TO THE UNION?',$)
        LEVEL=10
        READ (5,500,ERR=10) UPAYRT
        IF(UPAYRT.GT.1.) UPAYRT=UPAYRT/1
                **00.
        GO TO 29
C
C       SAVINGS SUBJECT TO UNION
650     TYPE 660
660     FORMAT(' WHAT IS THE LABOR SAVIN
                **GS PER YEAR THAT I
                **S',/
        1,' SUBJECT TO UNION PAYOUT?',$)
        LEVEL=8
        READ (5,500,ERR=10) LABORS
        GO TO 27
C
C       SAVINGS NOT SUBJECT TO UNION PAY
                **OFF
670     TYPE 680
680     FORMAT(' WHAT IS THE ANNUAL SAVI
                **NGS NOT SUBJECT TO
                **',/
        1,' UNION PAYOUT?',$)
        LEVEL=11
        READ (5,500,ERR=10) SNSUP
        GO TO 30
C
C       STOP PAYING OFF UNION
690     TYPE 700
700     FORMAT(' FOR HOW MANY YEARS WILL
                ** SAVINGS BE PAID T
                **O THE UNION?'
        1,$)
        LEVEL=9
        READ (5,420,ERR=10) PAYSTP
        I=LIMIT-ICOMP
        IF(PAYSTP.GE.0.0.AND.PAYSTP.LE.I
                **) GO TO 28
        TYPE 710,LIMIT
710     FORMAT(' THERE MUST BE BETWEEN Z
                **ERO AND ',I2,' YEA
                **RS.')
        GO TO 690
C
C       INFLATION RATES
720     TYPE 730
730     FORMAT(' WHAT IS THE INFLATION R
                **ATE FOR:',/
        1,' MATERIALS (IN PERCENT)?',$)
        LEVEL=14
        READ (5,500,ERR=10) MATINF
        MATINF=1+(MATINF/100.)
        TYPE 740
740     FORMAT('+LABOR (IN PERCENT)?',$)
        READ (5,500,ERR=10) LABINF
        LABINF=1.+(LABINF/100.)
        TYPE 750
750     FORMAT('+SAVINGS NOT SUBJECT TO
                **UNION PAYOUT'
        1,' (IN PERCENT)?',$)
        READ (5,500,ERR=100) OINF
        OINF=1.+(OINF/100.)
        GO TO 33
C
        END
C
C
C
C       PRINT THE CONTENTS OF DATA
        SUBROUTINE PRINT($,MATCH)
        COMMON LINES,DATA(26,2,10),POINT
                **(10),LABEL(10,2),W
                **IDTH(2)
        1,YLABEL(40),XLABEL(2),LIMIT,ICO
                **MP,X,NCAR,ATTRAT,M
                **ATINF
        2,LABINF,LABORS,LOW,HIGH,PAYSTP,
                **FRAC,FRIDT,TAXRAT,
                **UPAYRT
        3,SCHED(25),SNSUP,OINF,METHOD,LI
                **FE
        REAL NCAR,MATINF,LABINF,LABORS
        INTEGER POINT,YEAR,HIGH,LOW,PAYS
                **TP
        MATCH=1
        DO 30 LINE=1,LINES
        TYPE 10,LINE,LABEL(LINE,1),LABEL
                **(LINE,2)
        1,XLABEL(1),XLABEL(2),(YLABEL(I)
                **,I=1,40)
10      FORMAT(//,' LINE NUMBER: ',I2,T2
                **0,'LABEL: ',2A5
        1,/,8X,2A5,2X,40A1)
        DO 30 I=1,POINT(LINE)
        TYPE 20,I,DATA(I,1,LINE),DATA(I,
                **2,LINE)
20      FORMAT(1X,I2,5X,F10.3,2X,F10.3)
30      CONTINUE
        RETURN 1
        END
C
C
C
C
C       GIVEN PARAMETERS FIND THE AMOUNT
                ** WHICH CAN BE SPEN
                **T PER
C       CAR FOR A VARIETY OF DISCOUNT RA
                **TES. STORE THE RES
                **ULTS
        SUBROUTINE SOLVE($,MATCH)
        DIMENSION A(26),B(26),START(26),
                **ANNUAL(26),TAXCR(2
                **6)
```

```
      1,DEPRT(26),OTHER(26),SAVING(26)
      COMMON LINES,DATA(26,2,10),POINT
     **(10),LABEL(10,2),W
     **IDTH(2)
      1,YLABEL(40),XLABEL(2),LIMIT,ICO
     **MP,X,NCAR,ATTRAT,M
     **ATINF
      2,LABINF,LABORS,LOW,HIGH,PAYSTP,
     **FRAC,FRIDT,TAXRAT,
     **UPAYRT
      1,SCHED(25),SNSUP,OINF,METHOD,LI
     **FE
      REAL NCAR,MATINF,LABINF,LABORS
      INTEGER POINT,YEAR,HIGH,LOW,PAYS
     **TP
      MATCH=1
C
C     COMPUTE CASH FLOWS FOR EACH YEAR
     **, PER DOLLAR OF RE
     **TROFIT COST
      ISTP=PAYSTP+ICOMP
      TAXCR(1)=0.0
      IF(LINES.GE.10) GO TO 310
      LINES=LINES+1
      DO 100 YEAR=1,LIMIT
C
C     IF SYSTEM NOT COMPATABLE THERE I
     **S A START-UP COST
      START(YEAR)=0.0
      IF(YEAR.LE.ICOMP) START(YEAR)=(1
     **/FLOAT(ICOMP)-ATTR
     **AT)*NCAR*
      1(MATINF**(YEAR-1))*-1
C
C     ANNUAL EXTRA COST OF ADV. BRAKIN
     **G & COUPLING
      ANNUAL(YEAR)=FRAC*ATTRAT*NCAR*(M
     **ATINF**(YEAR-1))*-
     **1
C
C     TAX CREDIT ONE YEAR AFTER INVEST
     **MENT
      IF(YEAR.EQ.1) GO TO 40
      TAXCR(YEAR)=(START(YEAR-1)+ANNUA
     **L(YEAR-1))*FRIDT*-
     **1
C
C     DEPRECIATION TAX CREDIT
40    DEPRT(YEAR)=0.0
      IF(YEAR.LT.2) GO TO 55
      DO 50 I=1,YEAR-1
50    DEPRT(YEAR)=DEPRT(YEAR)-TAXRAT*(
     **START(YEAR-I)+ANNU
     **AL(YEAR-I))
      1*SCHED(I)
C
C     LABOR SAVINGS
55    SAVING(YEAR)=0.0
      UNION=1.0
      IF(YEAR.LE.ISTP) UNION=1.0-UPAYR
     **T
      IF(YEAR.GT.ICOMP) SAVING(YEAR)=L
     **ABORS*(1.0-TAXRAT)
     ***UNION
      1*(LABINF**(YEAR-1))
C
C     SAVINGS NOT SUBJECT TO UNION PAY
     **OFF
      OTHER(YEAR)=0.0
      IF(YEAR.GT.ICOMP) OTHER(YEAR)=SN
     **SUP*(1.-TAXRAT)*(O
     **INF**(YEAR-1))
C
C     FIND SUM OF PER COST CASH FLOWS
      A(YEAR)=START(YEAR)+ANNUAL(YEAR)
     **+TAXCR(YEAR)+DEPRT
     **(YEAR)
C
C     FIND SUM OF FIXED FLOWS
      B(YEAR)=SAVING(YEAR)+OTHER(YEAR)
C
C     CASH FLOWS IN YEAR = AX+B WHERE
     **X=COST OF RETROFIT
     **TING ONE CAR
100   CONTINUE
C
C     FIND PRESENT VALUE OF A AND B FO
     **R ALL DISCOUNT RAT
     **ES
      DO 300 I=LOW,HIGH
      SUMA=0.0
      SUMB=0.0
      R=1.0+FLOAT(I)/100.0
      DO 200 YEAR=1,LIMIT
      FACTOR=R**(YEAR-1)
      SUMA=SUMA+A(YEAR)/FACTOR
      SUMB=SUMB+B(YEAR)/FACTOR
200   CONTINUE
C
C     FILE RESULTS
      ROW=I-LOW+1
      DATA(ROW,1,LINES)=I
      XX=0.0-SUMB/SUMA
      DATA(ROW,2,LINES)=XX
      IF(I.EQ.12) XY=XX
300   CONTINUE
      POINT(LINES)=HIGH-LOW+1
C
C     COMPUTE PAYBACK PERIOD
      CUME=0.0
      DO 400 I=1,LIMIT
      CUME=CUME+XY*A(I)+B(I)
      IF(CUME.GE.0.0) GO TO 410
400   CONTINUE
      TYPE 405
405   FORMAT(' PAYBACK NOT REACHED.')
      RETURN
410   TYPE 420,I
420   FORMAT(' PAYBACK REACHED ',I2,'
     **YEARS AFTER START-
     **UP.')
      RETURN
      RETURN
310   TYPE 320
320   FORMAT(' DATA FILE IS FULL.')
      RETURN 1
      END
C
C
C
```

```
C       SOLVE WITH VARIABLE CASH FLOWS
        SUBROUTINE VARIA($,MATCH)
        DIMENSION A(26),B(26),START(26),
                **ANNUAL(26),TAXCR(2
                **6)
        1,DEPRT(26),OTHER(26),SAVING(26)
        COMMON LINES,DATA(26,2,10),POINT
                **(10),LABEL(10,2),W
                **IDTH(2)
        1,YLABEL(40),XLABEL(2),LIMIT,ICO
                **MP,X,NCAR,ATTRAT,M
                **ATINF
        2,LABINF,LABORS,LOW,HIGH,PAYSTP,
                **FRAC,FRIDT,TAXRAT,
                **UPAYRT
        1,SCHED(25),SNSUP,OINF,METHOD,LI
                **FE
        REAL NCAR,MATINF,LABINF,LABORS
        INTEGER POINT,YEAR,HIGH,LOW,PAYS
                **TP
        DATA SAVING/30.,60.,90.,120.,150
                **.,5*158.,15*537.,0
                **./
        DATA OTHER/1.,2.2,3.4,4.6,5.8,20
                ***59.2,0./
        MATCH=1
C
C       COMPUTE CASH FLOWS FOR EACH YEAR
                **, PER DOLLAR OF RE
                **TROFIT COST
        TAXCR(1)=0.0
        IF(LINES.GE.10) GO TO 310
        LINES=LINES+1
        DO 100 YEAR=1,LIMIT
C
C       IF SYSTEM NOT COMPATABLE THERE I
                **S A START-UP COST
        START(YEAR)=0.0
        IF(YEAR.LE.ICOMP) START(YEAR)=(1
                **/FLOAT(ICOMP)-ATTR
                **AT)*NCAR*
        1(MATINF**(YEAR-1))*-1
C
C       ANNUAL EXTRA COST OF ADV. BRAKIN
                **G & COUPLING
        ANNUAL(YEAR)=FRAC*ATTRAT*NCAR*(M
                **ATINF**(YEAR-1))*-
                **1
C
C       TAX CREDIT ONE YEAR AFTER INVEST
                **MENT
        IF(YEAR.EQ.1) GO TO 40
        TAXCR(YEAR)=(START(YEAR-1)+ANNUA
                **L(YEAR-1))*FRIDT*-
                **1
C
C       DEPRECIATION TAX CREDIT
40      DEPRT(YEAR)=0.0
        IF(YEAR.LT.2) GO TO 55
        DO 50 I=1,YEAR-1
50      DEPRT(YEAR)=DEPRT(YEAR)-TAXRAT*(
                **START(YEAR-I)+ANNU
                **AL(YEAR-I))
        1*SCHED(I)
C
C       LABOR SAVINGS
55      UNION=1.0
        IF(YEAR.LE.PAYSTP) UNION=1.0-UPA
                **YRT
        SAVING(YEAR)=SAVING(YEAR)*100000
                **0.
        SAVING(YEAR)=SAVING(YEAR)*(1.0-T
                **AXRAT)*UNION
        1*(LABINF**(YEAR-1))
C
C       SAVINGS NOT SUBJECT TO UNION PAY
                **OFF
        OTHER(YEAR)=OTHER(YEAR)*(1.0-TAX
                **RAT)*(OINF**(YEAR-
                **1))
C
C       FIND SUM OF PER COST CASH FLOWS
        A(YEAR)=START(YEAR)+ANNUAL(YEAR)
                **+TAXCR(YEAR)+DEPRT
                **(YEAR)
C
C       FIND SUM OF FIXED FLOWS
        B(YEAR)=SAVING(YEAR)+OTHER(YEAR)
C
C       CASH FLOWS IN YEAR = AX+B WHERE
                **X=COST OF RETROFIT
                **TING ONE CAR
100     CONTINUE
C
C       FIND PRESENT VALUE OF A AND B FO
                **R ALL DISCOUNT RAT
                **ES
        DO 300 I=LOW,HIGH
        SUMA=0.0
        SUMB=0.0
        R=1.0+FLOAT(I)/100.0
        DO 200 YEAR=1,LIMIT
        FACTOR=R**(YEAR-1)
        SUMA=SUMA+A(YEAR)/FACTOR
        SUMB=SUMB+B(YEAR)/FACTOR
200     CONTINUE
C
C       FILE RESULTS
        ROW=I-LOW+1
        DATA(ROW,1,LINES)=I
        DATA(ROW,2,LINES)=-1*SUMB/SUMA
300     CONTINUE
        POINT(LINES)=HIGH-LOW+1
        RETURN
310     TYPE 320
320     FORMAT(' DATA FILE IS FULL.')
        RETURN 1
        END
```

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