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HUMAN FACTORS IN RAILROAD OPERATIONS: INITIAL STUDIES

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16. Abstract

This report summarizes the progress of a year's work in providing support in human factors to the Federal Railroad Administration. The principal topics include: (a) a description of the locomotive engineer's job, particularly with regard to its inherent hazards, its contributions to operational safety, and the aptitudes and skills required for effective train handling, (b) an initial assessment of the physical fitness requirements for several railroad jobs, (c) an analysis of the needs for human factors data in accident reports, and (d) recommendations for the use of a locomotive and train simulator for research in railroad safety. Plans are given for continuation of the effort and recommendations for additional areas of study.

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PREFACE

This report represents the joint efforts of several staff members at the Transportation Systems Center and a consultant. The opinions expressed are those of the authors and do not necessarily reflect the policy of either the Transportation Systems Center or the Federal Railroad Administration. Authors of the technical chapters were:

Donald B. Devoe	Job Analysis of the Engineer
E. Donald Sussman	Physical Standards for Railroad Employees
C. E. Feehrer	Accident Analysis
J. H. Hill	Simulation Requirements
Wilfred H. Holland	Task Analyses for Medical Standards

Other members of the TSC staff who made significant contributions to the report were C. N. Abernethy and Anne W. Story.

The work represented by this report required the cooperative efforts of many people throughout the government and industry. Special thanks are due to the project monitor, L.G. Regan, and to J. Rourke, Director of Standards, Federal Railroad Administration. Organizations meriting special recognition for their willing assistance in our efforts to obtain factual data on railroad operations are:

The Atchison, Topeka and Santa Fe Railway Company
The Boston and Maine Corporation
The Penn Central Transportation Company
The Southern Pacific Transportation Company
The Brotherhood of Locomotive Engineers
The United Transportation Union
The Association of American Railroads

Finally, our special thanks are offered to the many railroad workers, active and retired, whose combined contributions through interviews and correspondence are responsible for whatever technical merit and authenticity this report may bear.

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The Department of Transportation's Transportation Systems Center (TSC) is conducting a continuing program of consultation and research in human factors for the Federal Railroad Administration (FRA), entitled: "Human Factors in Railroad Operations". The purpose of the program is to provide the technical skills and knowledge in areas related to human behavior needed by the FRA in support of their efforts to promote safety in railroad operations.

This report summarizes the work accomplished in Fiscal Year 1972 on this project.

1.2 BACKGROUND

1.2.1 <u>Requirements of Federal Railroad Safety Act</u>

Public Law 91-458; 84 Stat. 971, "The Federal Railroad Safety Act of 1970", provides in part that, in order to promote safety in all areas of railroad operations, the Secretary of Transportation shall:

> ....(1)prescribe, as necessary, appropriate rules, regulations, orders, and standards for all areas of railroad safety supplementing provisions of law and regulations in effect on the date of enactment of this title, and (2) conduct, as necessary, research, development, testing, evaluation, and training for all areas of railroad safety.

The Federal Railroad Administration was delegated the responsibility for implementing this act. Recognizing that in an industry employing over half a million personnel, human performance must be a significant contributory factor in operational safety, the FRA sought professional guidance on human factors. Essentially, what the FRA needed to know was the answers to such questions as:

a. How can human error contribute to railroad accidents?

b. Is Federal regulation necessary to assure safety?

c. If so, what standards or countermeasures are desirable?

d. How can these standards be enforced?

Human factors specialists were needed to apply what is known about human behavior in answering these questions and to plan and conduct whatever research might be needed where adequate answers were not available.

1.2.2 Initial Steps

Prior to TSC's participation, the SysteMed Corporation was engaged to conduct a survey of human factors affecting the safety of railroad operations. Their report to the FRA (Hanks and Walsh, 1971) reviewed accident data, U.S. and foreign literature, and current legislation, supplemented by field observations of railroad operations. They recommended a six-year research and development program in human factors, with special attention to accident investigation and reporting, communications systems, operating rules, work fitness, equipment design for human use, and training.

The establishment of the Transportation Systems Center as a research and development resource organization for the Department of Transportation in mid-1970 provided the in-house body of human factors specialists needed to undertake the program outlined by SysteMed. Consequently, a Program Plan Agreement (PPA-RR-209, Human Factors in Railroad Operations) was negotiated, giving TSC the responsibility of planning and managing a support program in human factors for the FRA and conducting such research as was within their capabilities.

1.2.3 General Approach

For any problem area, the general approach of the human factors support program includes each of the following steps to some degree. The nature of the problem area and the state of knowledge in human behavior will emphasize different aspects of the approach for different problem areas.

a. Study the Problem

- Analyze the job
- Review the literature
- Conduct supporting research
- Formulate tentative recommendations
  (Is regulation needed?....If so, what kind?)

b. Review and Submit Recommendations

- Obtain professional reviews of recommendations
- Revise recommendations and submit to FRA

c. Enact Regulations

- (An FRA function)

d. Assist FRA in Regulation Evaluation

- Evaluate regulation enforcement
- Develop aids for training and evaluation

Some of the areas selected for study as possible areas of regulation include:

- Physical fitness
- Use of alcohol and drugs
- Psychological fitness
- Level of training
- Contents and format of operating rules
- Communications and signals
- Design of equipment[1]

Support areas deserving additional research include:

- Job analyses
- Accident analysis and reporting
- Physiological and psychological stress
- Simulation
- Proficiency and aptitude evaluation
- Training methods and aids
- Vandalism

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1 Any reference to system or equipment design and analysis in this report implies simply that appropriate human factors contributions to the total design or analysis effort will be made.

Putting these elements together on a time scale, based on priorities jointly agreed upon by TSC and the FRA, yields the project structure outlined in Table 1-1. The activities listed under FY'72 are covered in this report. The activities for FY'73 have been started. Plans beyond FY'73 are tentative; they are subject to revision to reflect changes in priority, results of initial studies and any other developments that may occur.

1.3 THE PROGRAM FOR FISCAL YEAR 1972

1.3.1 Principal Activities

The principal elements of the FY'72 program were:

a. A job analysis of the locomotive engineer

b. Physical fitness requirements for railroad employees

c. Accident analysis and reporting

d. Requirements for simulation in research and training

Subsequent sections (2,3,4 and 5) in this report will describe in detail the problems, procedures and findings covered in these areas.

1.3.2 Support Activities

The FRA arranged for three tasks in support of this program to be conducted by the Human Factors Division, Crane Naval Ammunition Depot, a group of human factors specialists located on a base containing several hundred miles of railroad. The tasks involved a survey of vandalism in railroads, a survey of locomotive cab designs, and general support for TSC field trials of in-cab physiological measurements (Section 3). Separate reports are being submitted by Crane in these areas.

1.3.3 Special Activities

A variety of special tasks evolved from the initial work on this project, including presentation of special briefings, attendance at meetings of professional railroad organizations, and

TABLE 1-1. PROJECT STRUCTURE

REGULATORY AREAS	FY'72	FY'73	FY'74	FY'75 & BEYOND
Physical Fitness	Study	Recommend	Evaluate	Modify & Evaluate
Alcohol and Drugs	Study	Recommend	Evaluate	Modify & Evaluate
Psychological Fitness			Study	Recommend, Evaluate
Level of Training		Survey	Recommend, Eval.	Modify, Evaluate
Operating Rules		Study, Recommend	Evaluate	
Communications and Signals			Study	Study, Recommend, Eval.
Design of Equipment			Study	Study, Recommend, Eval.
SUPPORT AREAS				
Job Analyses	Engineer	Train, Road Crews	Switch, Dispatch	
Accident Analyses	Study	Model	Application	
Physiological Stress	Study	Field Tests	Field Tests	Simulator Tests
Simulation	Study, Recommend	Procure	Install	Conduct Simulator Res.
Proficiency Tests			Develop	Test & Recommend
Training Aids			Develop	Test & Recommend
Vandalism	Study & Recommend			

support to the Locomotive Control Compartment Committee.

1.3.3.1 Briefings - In order to obtain the cooperation of interested groups in future evaluations and field studies, it was considered desirable to inform them of the aims and procedures of the project as early as possible. In FY'73 special briefings were given to the Administrator and his senior staff at the FRA, to the United Transportation Union, to the Brotherhood of Locomotive Engineers, and to the Association of American Railroads.

1.3.3.2 Meetings - One way to learn quickly of special problems in a professional area is to attend a meeting of an associated professional organization. This activity also provides personal introduction to the leaders in the field. The staff of TSC was represented in FY'73 at meetings of the Railway Fuel and Operating Officers Association, the New England Railroad Club, and the Operating Rules Association.

1.3.3.3 Locomotive Control Compartment Committee - Concerned over the high death rate in locomotive cabs involved in collisions, an *ad hoc* committee including government, labor and management representatives has undertaken a study of cab design aimed at increasing cab safety. A TSC staff member attended several of the committee's meetings, functioning as a special consultant in human factors. The Crane survey of cab designs (Section 1.3.2) was established to assist this effort; its report constituted a useful reference both for the committee and for TSC's continuing efforts in this area.

2.0 JOB ANALYSIS OF THE ENGINEER

2.1 INTRODUCTION

2.1.1 Purpose and Scope

This section is a progress report of an ongoing analysis of the tasks performed in the operation of a railroad and their implications for the safety of the operations. A year's study is summarized. Although the analysis of the locomotive engineer's job is incomplete, it is possible to give a narrative description of typical aspects of the job and to derive tentative conclusions regarding the relationship between train handling and safety.

Detailed task analyses are basic to any human factors study of an operation. Each job in the operation is identified; the functions performed on the job are defined; the tasks to be accomplished in performing the functions are delineated, step by step; for each step detailed requirements are specified, including as a minimum:

a. Information needed to perform the task;

b. Information processing and decision making required;

c. Action required to complete the task.

From such data it is possible to specify such requirements as information sources (displays, signals, rules, orders, etc.), controls (levers, knobs, switches, buttons, etc.) and working environment (work space, display/control layouts, illumination, etc.), and also possible to deduce manning and training requirements. Task analyses are basic for evaluating the safety and effectiveness of job performance.

To provide a data base for consultation with the FRA on human factors in railroad safety, TSC has undertaken a continuing effort aimed at describing in detail all of the jobs involved in operating a railroad safely.

2.1.2 Approach

2.1.2.1 Priorities - Because of the kinetic energy under his control and its potential to do damage if not controlled, the locomotive engineer was given top priority for analysis. Other train crewmen (conductor, firemen, brakeman, flagman) were assigned the next priority. Attention will be focused later on yard crews, road maintenance crews, switching and dispatching functions and such other jobs as the FRA may designate.

2.1.2.2 Titles - The titles used for jobs in these analyses are functional rather than administrative. The term engineer throughout this report will refer to the person in charge of and responsible for the operation of the locomotive. This function will generally be included in the duties of jobs bearing the designations engineer, engineman, and hostler. If he is a qualified engineer or an engineer-trainee, the fireman may also perform the tasks of the engineer.

2.1.2.3 Phases of Analysis - The analysis of the engineer's job is proceeding in five phases:

a. Literature review

b. Consultation and observation

c. Task hazard evaluation

d. Field verification

e. Reporting

The literature that has been reviewed has included FRA technical reports, the operating rules and air brake manuals of several carriers, manufacturers' manuals for locomotives, the Air Brake Association's manual: Modern Freight Train Handling, the Railway Fuel and Operating Officers Association's manuals: Diesel-Electric Locomotives and The Modern Locomotive Handbook, laws and regulations on locomotive and air brake safety and numerous trade journals.

Experienced operating personnel from several commercial carriers have been consulted; visits have been made to observe yard and road operations; and check rides have been taken in the cabs of both freight and passenger trains on regular runs of four carriers.

The FRA has contracted with the McDonnell Douglas Electronics Company to perform a detailed analysis, step by step, of the various tasks performed by the engineer and to rate these for difficulty and hazards. Upon completion of the McDonnell Douglas analysis, field trips will be scheduled to selected carriers to verify the McDonnell Douglas and TSC conclusions, and a technical report will be prepared and submitted to the FRA.

2.1.2.4 Progress - The first two phases have been completed for the engineer. The McDonnell Douglas evaluation of hazards is in progress. Initial task listings have been prepared for all train crew jobs. Field trips are being planned; a round-table discussion technique has been developed and tested as a part of the field study approach. A report on all train crew jobs is scheduled for June 30, 1973.

2.1.3 Material to be Reported

The balance of this section will summarize the information gained to date on the job of the engineer. Section 2.2 reviews the tasks involved in handling a train and the numerous factors that can complicate the safe performance of the job. Section 2.3 derives relationships between the engineer's job performance and operational safety, both through a review of accident reports and statistics and an analysis of hazards inherent in the job situation. Section 2.4 draws tentative conclusions regarding the physical and psychological traits and the job knowledge and skills necessary for proficiency as a locomotive engineer.

2.2 ELEMENTS OF TRAIN HANDLING

2.2.1 Introduction

The methods of handling trains vary considerably as a function of the nature of the job, the equipment, the road and a variety of other factors. However, from the point of view of the skills required of the engineer, the problems associated with road freight operations are either typical or generally more severe than the problems of yard switching service and passenger service. Therefore, unless otherwise specified, the following discussion of train handling assumes diesel-electric locomotive equipment in road freight operations.

2.2.2 Train Control

The engineer generally controls the motion of trains. Because of the tremendous mass of a train, often thousands of tons, the kinetic energy involved is large, even at slow speeds, and the potential for causing damage and destruction is great if control is lost. Therefore the engineer plays a critical role in assuring safety of railroad operations.

The engineer exercises control of his train through a judicious and complex application of combinations of power and brakes. Power application is controlled by a throttle, generally calibrated for eight or more power settings. There are usually two or three braking systems available to the engineer.

The engineer's control position is a seat looking forward at the center of the right-hand side of the cab. Within reach of the seat, but varying in exact location in different locomotives, is a control stand. The principal power control is a throttle lever, generally at hand height for the seated operator. It has an idle position at the right of its excursion and eight or more notched positions to the left representing increasing power settings. The stand also has a selector lever for setting power and dynamic braking modes, and a reverse lever, with positions REVERSE, OFF, and FORWARD from left to right. (When a locomotive is left standing with the engine idling, the reverse lever generally removed, acting as a "key" for the locomotive). A separate stand near the control stand holds the air brake control valves. On or near the control stand, an instrument panel contains pressure gauges, ammeter, speed indicator, warning lights, and some selector switches. Controls for horn, bells, sanders, and safety devices are generally on or near the instrument panel. All cabs contain the same kind of basic controls and displays, but the design and arrangement vary vastly from model to model.

2.2.3 Power

Power is generated in a diesel-electric locomotive by a diesel engine that drives a main generator supplying electricity to a set of traction motors geared to the axles. The number of diesel engines and traction motors in a locomotive may vary, and several locomotives may be coupled together to form an engine "consist", but these units, if properly equipped, can be so connected that the engineer controls the total power with one throttle in the lead cab, as if it were a single unit.

The power necessary to achieve a given speed is a function of the mass of the train, the conditions of the track, and the grade and curvature of the track. The engineer senses most of these effects from the feel of the train. A load indicating meter in the cab shows the current being drawn from the generator by the motors; it is used to determine when the throttle can be advanced or should be reduced. A wheel-slip light on the engineer's instrument panel illuminates when traction is lost, the response to which is to sand the track by manipulation of a sander valve or switch, (this function is often automated). A speed indicator, calibrated in miles-per hour, is mounted in a prominent position in the cab. These controls and displays constitute the basic system for the engineer's control of power in managing movement of the train. (An exception is the special case of dynamic braking which will be included in the discussion of the braking system).

2.2.4 Braking

In addition to increasing or decreasing tractive power, the engineer controls his train by applying braking forces. For this purpose he has three braking systems. Two are always available: the automatic train brake and the independent engine brake. The third, dynamic braking, is optional but is in wide usage. As with power, multiple unit trains can be arranged so that the engineer controls all air and dynamic brakes from one cab. Two additional braking features, hand brakes and pressure retainers, are available but can not be controlled from the cab.

2.2.4.1 The Automatic Train Brake - The automatic train brake is an air brake system. The diesel engines, both when idling and when powering the train, operate air compressors that store a supply of compressed air in a main storage reservoir in each locomotive. The heart of the automatic brake system is the brake pipe, a continuous set of coupled pipes and hoses which runs the entire length of the train. When cars are coupled to the train, the brake pipe sections are also coupled. The brake pipe is normally charged to a standard pressure from the main reservoir. Every car and locomotive has a brake system controlled form the brake pipe by a control valve which is held closed by the brake pipe pressure. A reduction in brake pipe pressure permits each control valve to open, releasing compressed air from an auxilliary reservoir on each car to enter an associated brake cylinder. Application of pressure in the brake cylinder operates through a mechanical linkage system to press a brake shoe against the tread of every wheel on the car, thus applying a braking force. Ideally, a reduction in brake pipe pressure results in an even application of braking force to every wheel on the train, and recharging the brake pipe releases the brakes. The reduction of brake pipe pressure, or the recharging of the brake pipe and the auxiliary reservoirs from the main reservoir, can be controlled by the engineer in his cab through the operation of the automatic brake valve located on a brake control stand at his operation position. The automatic brake system is "fail-safe" in that loss of pressure in the brake pipe through leakage, accidental rupture or breaking apart will cause the brakes to apply.

2.2.4.2 The Independent Brake - The independent brake system permits the engineer to apply or release the air brakes of his locomotives independently of the brakes on the rest of the train. Thus he can brake only the locomotives, or he can brake the entire train with the automatic brake and release the locomotive brakes. This brake system is controlled by the independent brake valve, located adjacent to (usually below) the automatic brake valve on the engineer's brake control stand.

2.2.4.3 Displays Related to Air Braking - The engineer is always provided with two air gauges on his control stand. One gauge shows pressures in the main reservoir (red hand) and an equalizing reservoir (white hand). The other gauge shows brake pipe (white hand) and locomotive brake cylinder (red hand) pressures. Many locomotive control stands now include a brake pipe flow indicator, which shows the rate of flow of air through the automatic brake valve to the brake pipe. Another optional gauge shows application and suppression pressures used in conjunction with certain safety devices operated from the compressed air system. The results of braking can be seen on the train speed indicator and can be sensed by the general behavior of the train. A new device has recently come into limited usage, called the Train Handling Indicator. This device moves a track contour chart across a rectangular window in synchrony with the motion of the train. Several miles of track, showing grades, curves, crossings and other features are always visible, the center of the display being the location of the cab. An indicator can be set for the length of the train. The engineer can thus see how his train is spread across curves and grades as well as what terrain and problem areas he is approaching. This information is useful to him in determining when to brake, and how much.

2.2.4.4 Other Brake Controls - Any valve that will evacuate the brake pipe can be used to stop a train. This feature is basic to a number of safety devices. An emergency brake application valve is always located on the left-hand side of the locomotive cab, permitting crew members other than the engineer to stop the train. Similar valves are located in the caboose of a freight train and in each car of a passenger train. The caboose may be equipped with a valve permitting graduated as well as full emergency applications of the brakes; often in backing operations a trainman standing on the lead platform of the caboose will use this valve to assit the engineer in maintaining a safe speed.

Several safety systems are available that will sense either lack of response from the engineer or excessive speed of the locomotive and sound an audible warning. If an appropriate response is not made by the engineer within a short time limit, a full service brake application occurs automatically, called a penalty application.

Each car of a train is equipped with a hand brake capability. Manual operation of a control (usually a large wheel) will apply the brakes of that car or locomotive mechanically. Hand brakes must be set and released car by car. They are used as required when locomotives or cars are left standing in a yard or siding.

Most cars are equipped with a valve that can be set manually to preserve a minimum pressure in the brake cylinder even when the brake pipe is fully charged (brakes released). This pressure retaining feature can be preset on a selected number of cars in a freight train to guarantee a minimum braking force in long downhill operations. Retainers can be set or released only when the train is standing still, and must be done manually, car by car.

The engineer can predetermine and order the use of hand brakes and retainers, but he can neither apply nor release them from the cab, nor can he receive information on their status from his instruments.

2.2.4.5 Dynamic Braking - This system is optional but is widely used. The electric traction motors in diesel-electric locomotives can be connected to act as generators, having a retarding effect on the wheels. The power thus generated is dissipated as heat through resistance grids in the roof of the locomotive. Dynamic braking is effective only when the locomotive wheels are turning; so there is a minimum speed below which is not effective. Because of the fixed load resistance, there is an optimum speed for the retarding force. For any brake setting, between the minimum and optimum speeds, the retarding force increases with speed; above the optimum, the retarding force declines with speed. Some locomotives now have a feature called extended range dynamic which brings the optimum speed (and therefore maximum retardation) down to the minimum speed.

The engineer uses the selector lever on his control stand to select either a power or dynamic braking mode of operation. In the dynamic braking mode, some control stands provide for the application of braking power by further motion of the selector lever to the right. On other locomotives, once dynamic braking mode is selected, the application of braking power is controlled by moving the throttle lever to the left (exactly as is done to apply tractive power in the power mode).

The load ammeter shows the current being used for braking. Modern ammeters have a dynamic braking zone to the left of the power zone, color coded yellow. Older equipment uses the load meter over a single zone to indicate either power or braking current. (The safety implications of the use of the throttle and load meter in precisely the same way for both power and braking will be discussed in paragraph 2.3.4.3).

Dynamic braking resembles the independent air brake in that braking is applied only to the locomotives. This generally implies the application of braking forces to the front end of the train only, although the control of a remote locomotive by radio signals makes it possible to put power and locomotive braking forces at the middle or rear of a train where the equipment is available.

A principal advantage of dynamic braking is that there is far less time lag between operation of control and response of train than with air brakes, thus allowing for fine adjustments in train speed. Dynamic braking also does not deplete the supply of compressed air, and it causes no wear on the brake shoes.

A principal disadvantage of dynamic braking is that it is applied only to the locomotives, thus concentrating braking forces in one part of the train and setting up compressive (buff) loads in the unbraked portion. As has already been noted, dynamic braking effectiveness varies with train speed and cannot be relied upon at very high and very low speeds. When combined with air braking, dynamic braking can create a braking force in excess of adhesive force as applied to the locomotive, causing the wheels to slide. If not corrected, wheel sliding will wear flat spots on the locomotive wheels.

A basic train handling skill requirement is the ability to combine air and dynamic brakes for smooth, safe operation of the train. Generally on long down grade runs, this amounts to setting a moderate braking force with the automatic train brake and using dynamic braking for fine adjustments in speed in response to changes in grade and track curvature.

2.2.5 Response Times in Train Operation

Because of the mass of a train (commonly from 4,000 to 15,000 tons in North America), changes in speed take a long time, during which the train covers a long distance. A 5,000 ton freight train pulled by four 3,000 hp units on level track will travel 1.2 miles from a stop to reach a speed of 40 mph; 5 miles to reach 60 mph, and 15 miles to reach 70 mph.

Operating rules require a train to be able to stop within one block between speed control signals. In North America, block distances are normally 5,000 ft. to 15,000 ft., so braking must act faster than acceleration. Even so, braking is a slow process. In a 150-car train, it can take three minutes before a 15 psi brake pipe reduction is effective on the rear car - that is, before the brakes on the rear car are fully applied - and more time elapses before the train stops. Emergency applications are fastest, but even they are far from instantaneous. Estimates based on a 3,500-foot train on level track indicate that 13.8 seconds elapse before full retardation is achieved. This train at 50 mph would travel over 2,000 feet after an emergency application before stopping; at 20 mph it would go over 350 feet, and at 10 mph it would still take 88 feet.

Release of brakes that have been applied also takes time, because the brake pipe and each car's auxiliary reservoir have to be recharged with compressed air. On passenger trains brakes can be successively applied and released in graduated amounts, but on long freight trains it is necessary to effect a complete release of brakes before a second application. With older equipment, long trains going less than 25 mph had to stop at least two minutes to release brakes (it can take 10 minutes to recharge a long train after an emergency application, which completely vents the system). Newer valves speed up release by recharging partially from each car's emergency reservoir; with this equipment, running releases are now possible. Still the engineer must continually anticipate substantially in advance any requirement for braking and plan the management of his brake system to achieve smooth, safe control.

2.2.6 Factors Complicating Train Handling

The systems whereby the engineer controls train movement, as described up to here, are relatively simple. Power is added or decreased by changing throttle setting. Braking force is applied throughout the train by incremental applications of the automatic train brake. Fine control of braking is achieved through the use of the independent brake and/or dynamic braking. However, numerous additional factors are always present to complicate the use of these control systems.

No two train runs are the same, generally for reasons beyond the control of the engineer. Therefore, to assure safe operation of his train, the engineer must learn as much as he can about these complicating factors and continually compensate for them in handling the train. For purposes of discussion, complicating factors have been grouped into three types: train factors, environmental factors, and operational factors. Train factors include both makeup of the train, (power and cars), and such dynamic factors as slack and braking. Environmental factors include track and terrain, grade crossings and weather. Operational factors include written instructions, signals, communications and crew interactions. How these factors affect train handling will be discussed in some detail.

2.2.7 Train Factors

2.2.7.1 General Train Makeup - No two trains in road freight operations are made up the same way. The loads and destinations, their order of arrival at the classification yard, the requirements for and availability of power units, and numerous other factors combine to create a consist of locomotives and cars, with a rated horsepower, total weight, length, and special features that the engineer learns only on signing in and picking up his train. Written material may give him such gross descriptive data; his crew will give him some additional information. However, he must learn the net result of many of these factors through sensing the response of the train as he controls it in motion.

2.2.7.2 Power Makeup - In road freight operations it is usual to connect several locomotives together into a multiple unit power consist. Each unit contains controls that the engineer can set so that all the power and train braking functions are controlled from one locomotive, generally the lead unit. The units may vary in horsepower, in power adjustments called transition, in the type of air brake valves installed, in age and condition and in physical layout of the controls. The engineer will be given a horsepower rating of his power consist and must learn whatever else he needs to know about the units by an initial inspection. Before moving the power consist, he will test the operation of air brakes and sanders.

Generally, power is concentrated at the front of the train. Two exceptions are remote control units and helpers. Equipment is now in use on some railroads permitting the engineer to control a second power consist in his train by radio signals. There is a considerable advantage gained in traction by having some of the power in the middle or at the rear of the train; the recharging of the air brake system is more rapid with compressors down the brake pipe. The engineer's job is more complicated, however, because he must operate an extra set of controls (throttle, brakes, sanders) and must continually anticipate the effects of power and braking as applied in two portions of his train.

A helper is an independent power consist (one or more locomotives), with a separate crew and controlled by its own engineer, attached to the rear of a train to give extra power, generally for mountain operations. If radio communication is available, the lead engineer can control the helper power by spoken instructions. If visibility conditions permit, hand signals may be used. Horn or whistle signals are sometimes used also. However, there are many situations where the lead engineer must rely solely on the skill and judgment of the helper engineer in the joint control of train power.

2.2.7.3 Makeup of Cars - Passenger trains may often repeat the same number and type of cars in their makeup. But every freight train has its individual characteristics, all of which complicate the handling of the train. The makeup is essentially random in nature, depending on what is being shipped, in what order the cars arrived at the classification yard, available power, destinations, and the like. A freight run may involve several pickups and drop-offs, so that the makeup varies from stop to stop.

There is a wide variety of freight cars, including box cars, tank cars, gondolas, hoppers, flat cars, piggy-backs, and many special cars. Each type of car can accommodate a variety of loads that can vary in weight, fragility and potential danger. Freight cars vary considerably in length, height and width. The type of brake valves and the condition of brake valves and brake pipe can vary from car to car. Some cars are equipped with box journals, others with roller bearings. Some may have cast iron brake shoes, others special composition brake shoes. The slack or "play" in the couplers and draft gear will vary from car to car.

When this heterogeneous collection is connected, there is a resultant weight and length of the train which are given in the engineer's orders and which are basic parameters in his train-handling decisions. However, the distribution of weight within the train further complicates safe train handling. A lightly loaded car will respond faster to a brake application than will a heavy car. Thus, if there is a concentration of light loads or empties near the front of the train, on application of the brakes the heavier rear will push up against the slower front portion with danger of buckling (jackknifing) and derailment. Conversely, with a light load on the rear, the train will tend to pull apart, possibly breaking in two. The engineer relies on his crew to note and report to him the location of light, heavy, high and wide sections and dangerous cargo, which they note on a walking inspection of the train or from the waybills. He then must keep all of this information in mind as he controls power and brakes.

2.2.7.4 Dynamic Factors - Train makeup, particularly on long freights, affects two important dynamic aspects of train handling: slack control and braking. Slack is the play in the coupling between cars. There may be as much as one inch of slack in a pair of joined couplers, and each draft gear in the attachment may have 2 to 3 inches, giving on the average about five inches of slack per car. In a 200 car train, the slack amounts to 100 feet of movement within the train. When all the slack is taken up (all cars as far apart as they can get), the train is said to be stretched. When all cars are pushed together as close as possible, slack is said to be bunched, or gathered.

If slack is stretched and the front of the train accelerated, the accelerating force is fully applied to all cars against resistive forces, and the train can break apart at a weak coupler. It may, therefore, be desirable to bunch slack before starting the train. This may be accomplished by applying the automatic train brake lightly, releasing the independent brake, and backing the train slowly until it stalls. Care must be taken in starting forward to move slowly and steadily, taking up the slack car by car; otherwise a series of jerks and jolts will occur through the train which can damage cargo and injure crewmen. On a moving train, slack can be bunched by applying only the independent or the dynamic brake gently, allowing the train to run in slowly. Again, if not handled smoothly, slack run-in can cause a highly undesirable series of jolts.

If a train is running on the level or approaching an upgrade, it is desirable to keep the train stretched. One technique for this is power braking, keeping the train under power with the independent brake released but with a light application of the automatic train brake.

Numerous other techniques are available for slack control. The point to be noted here is that with a long train, unevenly distributed load, and undulating terrain, slack control alone poses a taxing problem for the engineer.

Train makeup also has effects on braking. There is never the ideal constant pressure throughout the train brake pipe. There is a taper, or gradient, in pressure in the brake pipe from front to rear due to inevitable leakage along the way. A brake pipe pressure gauge is always installed in the caboose and must be frequently monitored by the rear-end crew to assure a safe pressure throughout the brake pipe. Variations in the leakage among the different cars in the makeup aggravate the gradient problem. Sometimes a small brake pipe pressure reduction initiated in the lead cab may fail to apply the brakes fully toward the rear, and if this is rapidly followed by a release (charging the brake pipe again), some control valves (and thus brakes) may stick.

Another leakage problem is in the brake cylinders. If the train brakes are constantly applied for a period of time (as in downgrade operation), different degrees of leakage in the cylinders on different cars will cause uneven application of brakes.

If the engineer attempts to compensate for the weakened brakes by a further application, too heavy an application will result on the "tight" cars, causing excessive brake shoe wear. An early technique for such a situation was "cycling", a periodic complete release of all brakes and then a reapplication. In downhill operations cycling gradually depletes the auxiliary compressed air reservoirs on the cars and also permits hazardous acceleration of the train during the "brakes-off" phases. One solution to the latter problem is to stop the train before a downgrade and manually set enough retainer valves to assure safe braking during cycling. In undulating terrain stopping to set, and then to release, retainers is undesirably time consuming. Furthermore, setting retainers does not assist in the conservation of compressed air.

There are automatic train brake valves widely in use now that have a pressure maintaining feature that senses changes in pressure in the brake pipe and automatically compensates for them, maintaining a constant pressure in the system against leakage. Pressure maintaining valves and dynamic braking eliminate the need for setting retainers and cycling. However, there are special precautions, too, that must be observed in the use of the pressure maintaining feature. Therefore, the engineer must be fully aware of the total brake system that has been given him in his train makeup and must make his train-handling decisions and actions compatible with what he has.

2.2.8 Environmental Factors

2.2.8.1 Track and Terrain - Adverse track conditions can seriously complicate train handling. Wet or greasy rails can affect adhesion, requiring variations in throttle settings, frequent sanding and reduction of speed. The engineer should take into account poor track conditions when he has high, wide and topheavy loads to estimate the potential of swaying cars.

Track grades complicate all throttle and braking adjustments, adding gravity effects to resistance in uphill operation, subtracting gravity effects in downhill operation. Track curvature increases resistance to motion and adds the hazard of centrifugal forces. When a long train is spread over several peaks and valleys of undulating terrain, particularly with many curves (typical of mountain operations), the engineer has to make frequent adjustments of power and brakes. Otherwise, his train can break in two going over a hump; he can experience rough slack run-in crossing a depression; he can stall on a steep upgrade, or he can lose control of his speed (runway train) on a downgrade.

Other terrain features, such as cuts and foliage, can interfere with the visibility of signals and hazards ahead or the condition of the train behind.

Switches, crossovers, frogs and some bridges or trestles may require speed reduction and other precautions.

2.2.8.2 Grade Crossings - Where roads and highways cross railroads at grade, the special hazard of train-automobile collisions exists. Although accounting for 15 percent of all railroad accidents of any kind, grade-crossing accidents account for 59 percent of all deaths related to railroad operations. Although the engineer is virtually helpless to prevent such accidents in terms of stopping his train short of an occupied crossing, he has a number of related tasks that complicate his job. He must sound a warning of his horn (or whistle) as he approaches designated crossings, while remembering at which crossings timetable orders forbid use of a warning due to local ordinances. Where crossings are numerous, the operation of the horn is almost continual. In switching operations across grade crossings, the engineer often must send out a flagman to control traffic, if crossing watchmen or automatic protection is not provided, and he must avoid setting off cars where they will operate the alarm at protected crossings, or have a trainman direct traffic.

2.2.8.3 Weather - Extremes of heat, cold and humidity complicate the engineer's job through discomfort in the cab. In extreme cold, brake pipe gradients increase, interfering with braking and requiring shorter trains to be run. All forms of precipitation can cause slippery rails and are joined by haze, blowing dust and fog as causes of reduced visibility, generally requiring operation at reduced speed. Strong winds can increase or decrease train resistance to motion. Deep snow and flooding on tracks can slow or stop operation.

2.2.9 Operational Factors

The engineer controls the motion of the train in response to numerous operationally determined requirements. These include a variety of written instructions, numerous signals and signs, radio communications and interactions with other crew members.

2.2.9.1 Written Instructions - Every carrier has a published set of operating rules that the engineer must carry with him while on duty. These rules define terms, specify rights and priorities, give examples of formats, picture and explain the meanings of signals, and codify whatever other information the carrier considers necessary to promote safe and efficient operation. The Association of American Railroads has published a standard code of rules; the carriers' individual codes are generally based on the AAR rules but modify and amplify them to adapt to their particular needs.

Every carrier publishes one or more timetables. In addition to showing routes and schedules, the timetable contains a variety of additional rules, especially the detailed rules and exceptions applicable to particular locations or routes. Crew members are required to carry the latest timetable while on duty.

Short-term changes in rules, special conditions and the like are published in special bulletins and posted on bulletin boards. Engineers must check these bulletins when reporting on duty to learn of any conditions applicable to them.

Written train orders and/or clearances may be required to control the movement and meetings of trains. The engineer must obtain, sign for, and read all such documents that define his assignments for the tour of duty.

The material immediately applicable to a given present or anticipated situation is scattered throughout these many documents. The engineer must learn how to read selectively, locate and memorize the parts of concern to him. He is expected to have committed to memory all of the operating rules; he has had to pass a test on the rules to qualify for his job and is generally reexamined on rules periodically. He should know the special conditions on his route covered by the timetable and from time-to-time may reread part of it and refresh his memory enroute. He must write down or memorize applicable information from bulletins. He signs for, reads and carries with him his train orders. He must integrate all of this information continually to guide him in the management of his train.

2.2.9.2 Signals - The need to start, stop or change speed of the train is generally made known to the engineer by a variety of signals. Fixed wayside signals are established at stations, block boundaries, interlocking boundaries, entrances to sidings, crossovers and wherever else speed requirements may change frequently. Wayside signals may be mechanical - semaphores are still widely in use. They may consist of one or more steady or flashing colored lights, or varying patterns of lights of one color. The signals may be controlled manually or automatically. Signals generally indicate the degree of clearance in the block or blocks ahead and signify a specific allowable speed in the block. Signal types vary considerably from carrier to carrier. The meanings (indications) are somewhat more standardized, but still differ between carriers, and in a few instances, identical signal aspects can have different meanings on different lines. Signal aspects and indications are always defined and pictured in the company's book of operating rules. The AAR rules define eighteen indications, with a variety of aspects for each. Most carriers use at least the AAR indications with some additional ones; a few carriers have managed to condense their requirements to less than the AAR.

Wayside signals are supplemented by a variety of boards, signs and flags, generally showing locations, fixed speed limits, or special conditions. Every mile of track is generally marked by a numbered milepost, the standard location reference for many instructions. Other signs include fixed speed limits, yard limits, station names, whistle boards and the like. Temporary colored boards or flags may be placed to show temporary speed restrictions.

Many railroads now have indicators installed in their locomotive cabs which duplicate the information given on wayside signals. Cab signals are either colored lights or light-pattern types. They not only overcome the problems associated with visibility restrictions outside the cab, they also show the engineer when conditions change while he is between signals, even giving an audible signal in some cases, and some cab signal systems will apply the brakes if the engineer fails to make an appropriate response. Cab signals do not show the engineer the location of the next signal.

Many train movements, particularly in switching, are controlled by hand or flag signals given by crew members at trackside. Hand signals are exchanged between crews of passing trains to indicate observed presence or lack of problems on the trains. At night, hand signals are given with lanterns. In emergencies, fusees (flares) are placed on or near the tracks as a warning to approaching trains to stop and investigate or to proceed with caution. Hand signals are also given with fusees. Torpedos can be attached to a track; when run over by a train, they explode loudly enough to be heard by the engineer as a warning of trouble ahead. The use of hands, flags, lanterns, fusees and torpedos as protective signals is generally referred to as "flagging".

2.2.9.3 <u>Communications</u> - Radio communications are becoming common in railroad operations. Communication with dispatchers used to require stopping the train and sending a crewman to a wayside telephone. Now the engineer can receive new orders directly from a dispatcher or operator and can call in with questions, a mixed blessing since several serious accidents have resulted from misunderstandings generated by poor communication procedures. Not all trains have functioning radio equipment, and the engineer must adapt regularly to what is assigned to him.

Intra-train communications are improving with the use of radios. In the past, the engineer has communicated to trainmen in the caboose or at trackside with whistle or horn signals, but could only get information from them via hand, flag or lantern signals. (In passenger trains, the conductor has had a means of operating a small whistle in the cab from his post in the train.) Radio equipment in the cab, permitting communication with the caboose and with walkie-talkies at trackside, greatly facilitates switching operations and keeps the engineer apprised of conditions at the rear. Such equipment also gives him direct contact with dispatchers and yard masters. However, radio usage is not universal, and where it is used, the engineer cannot always count on having a radio in the equipment assigned to him. Trackside telephones and pickup of written orders at intermediate stations still constitute principal sources of information for engineers.

2.2.9.4 Crew Interactions - Finally, the engineer regularly receives information from the other crew members in the cab. Operating rules generally require that any railroad employee riding in the cab must keep a lookout for wayside signals, broken track, obstructions in the track and the like. The aspect of each signal must be called aloud by each crewman as soon as sighted. Other front crewmen may send and receive messages for the engineer via radio, hand signals, or (when stopped) telephone.

Calling signals has been a primary cab duty of firemen and anyone else in the cab. Laws and labor agreements are changing and gradually reducing requirements for carrying a fireman on freight operations. Most freight train crews include a front-end brakeman who generally rides in the cab. Road foremen and other supervisors frequently ride the cab to check on operations, and trainees may be there to observe and learn. So the engineer is seldom alone, and he may have several companions in the cab. When rules are strictly observed, safety is enhanced through the combined monitoring of signals and conditions by several people. However, cab companions inevitably draw engineers into conversations, discussions, arguments and the like and can provide distractions that are undesirable.

Variations in labor agreements, availability of personnel, absenteeism and many other factors combine to prevent the creation and maintenance of crew teams. The engineer typically works with a different crew on every run, and although he may work often with the same conductor or trainmen, he must continually assess and adjust the confidence he can place in the competence of his fellow crewmen. This situation puts additional stress on the engineer as the one who must take all factors into account to assure safe movement of his train.

2.3 IMPLICATIONS FOR SAFETY

2.3.1 Introduction

The foregoing breakdown of the job of the locomotive engineer was developed as a background for the determination of the engineer's role in railroad safety. There are two approaches to such a determination: statistical and analytical.

The statistical approach to the engineer's role in safety involves the systematic summary and interpretation of what effects the engineer's performance has had on safety in the past. If we are aware of how engineers have caused accidents in the past and how frequently and consistently these events have occurred, then we can identify those aspects of engineer performance that have been critical for safety in the past and are likely to be in the future. This information is important in assigning priorities to corrective efforts.

The analytical approach involves examining each task the engineer performs and asking such questions as: What could go wrong? Could the engineer make a mistake? How serious would such an error be? Such an analysis gives guidance as to what could cause an accident, and estimates can be made as to the likelihood of such occurrences.

To a great degree, we might expect that an analysis of what could occur would create a pattern of events that would match what statistics show us has occured. However, when causation factors are complex, events are relatively infrequent, and the statistics available are limited, the two patterns may not match well. Particularly, when situations exist that are potentially dangerous in the opinion of professional analysts, they merit consideration for correction even though they may not have caused much trouble in the past. Their potential as future causes of accidents can not be taken lightly.

Another reason for not relying wholly on the statistical approach as a basis for priorities lies in the difference between causes of accidents and the consequences. When a railroad accident may have cost in deaths, injuries and dollars is not an accurate predictor of what another accident of similar causes might cost in the future. For example, several collisions between trains may have occurred because of similar human failings in the crew but with statistically negligible costs in deaths and injuries. However, the next accident of this type might let loose an explosive, flammable or toxic load from broken cars into a thickly populated surrounding. The statistics help us predict what kinds of accidents are most likely to occur, but they do not permit us to predict accurately what the costs may be. Because of such considerations, we are pursuing both the statistical and the analytical approaches.

2.3.2 Statistical Information

The Office of Safety of the FRA maintains accident records and publishes summary reports both monthly and annually. Any railroad accident involving damage in excess of $750 and involving a train is defined as a "train accident". Any accident involving a train in which damage is less than $750 but in which deaths or injuries occur is reportable as a "train service accident". Accidents in railroad operations causing deaths or injuries but not involving trains are reportable as "nontrain accidents". Each class of accident is reported in a different format, and the statistical summaries thus contain different parameters, particularly with regard to causative factors.

2.3.2.1 Accident Statistics - Figure 2-1 shows the deaths, Figure 2-2 the inuries, reported to the Office of Safety for railroad accidents over a six-year period (1966 through 1971). There is a heartening tread toward fewer deaths and injuries over these years in all classes of accidents; however, the totals are still high enough to be of serious concern.. The proportions of casualties due to various classes of accidents are fairly stable over this period. By definition, the train accidents cause the most damage. However, they account for a relatively small percentage of casualities. Nontrain accidents account for even fewer deaths but many more injuries. Train service accidents account for the great majority of deaths, and a good two-thirds of these are due to train-car collisions at grade crossings (plotted separately in Figures 2-1 and 2-2). Although the proportion of injuries at grade crossings is lower, it still amounts to over 3,000 per year.

As a numerical basis for further comparisons, Office of Safety figures were averaged over the years 1968, 1969, and 1970 for selected categories of information. Some of these results are shown in Table 2-1. We can see that the 15 percent of accidents that occur at grade crossings account for 59 percent of all railroad-related deaths and 15 percent of the injuries. The grade-crossing accident is generally the fault of the automobile driver. We have already noted in Section 2.2.5 how far a train can move after application of emergency brakes; there is virtually nothing the locomotive engineer can do to prevent this type of accident. The National Highway Transportation Safety Administration and the FRA are conducting joint research on human factors in grade-crossing accidents.

The way the statistics are reported makes it very difficult to estimate the degree to which engineer errors contribute to the train service casualties other than those at grade crossings. In the period 1968-1970, falls, burns, and miscellaneous accidents

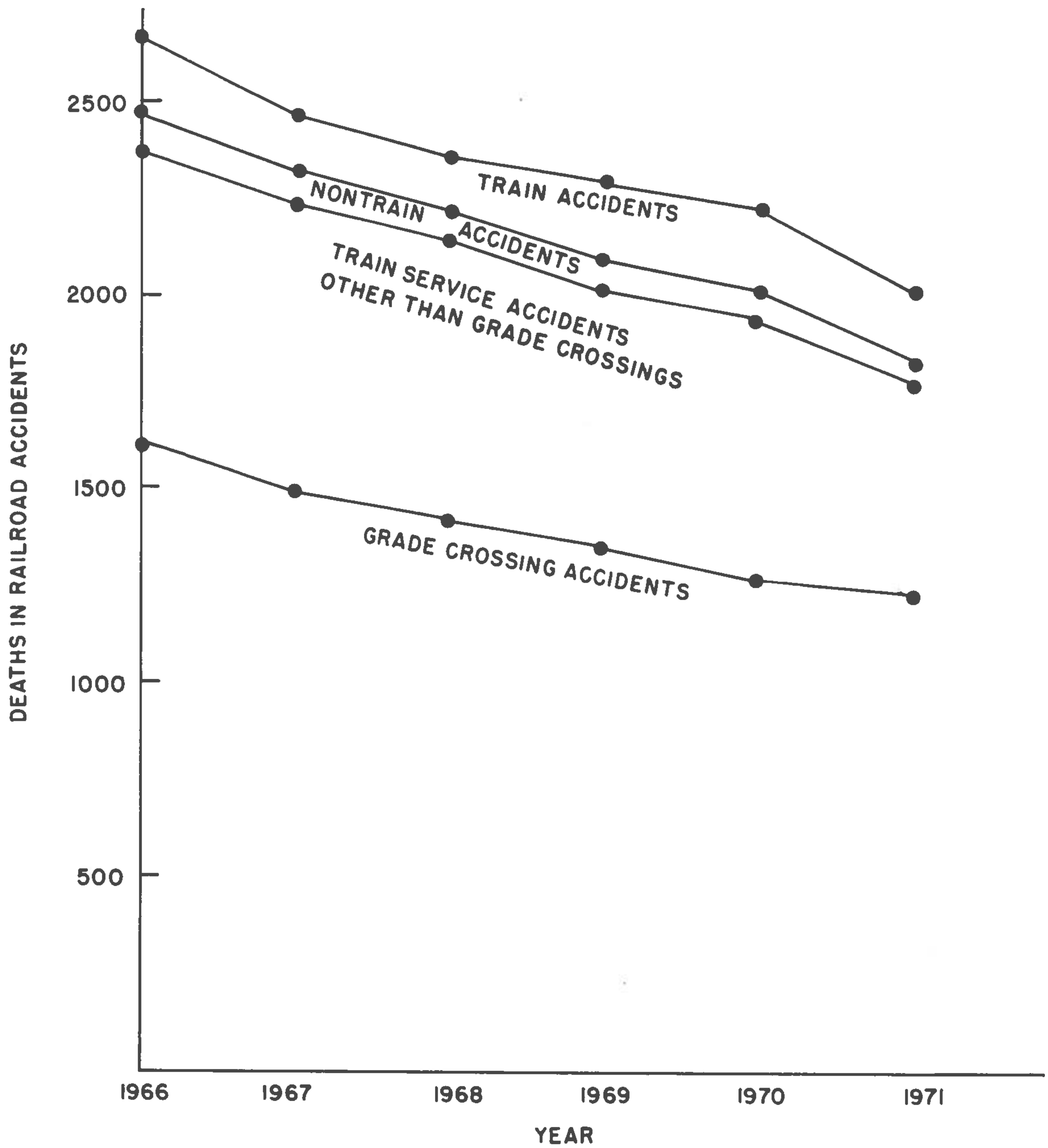

Figure 2-1. Deaths in Railroad Accidents, 1966-1971

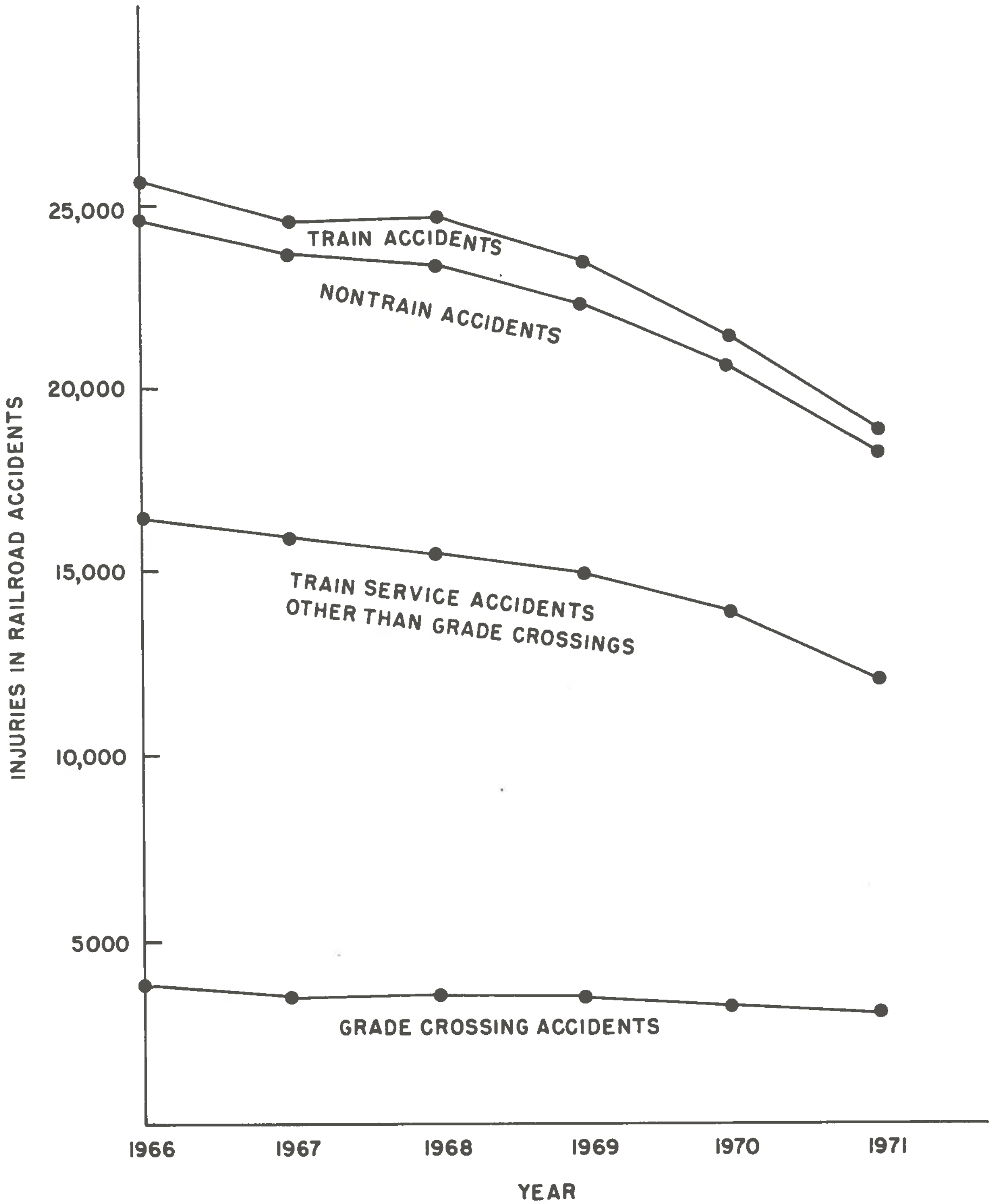

Figure 2-2. Injuries in Railroad Accidents, 1966-1971

TABLE 2-1. ANNUAL CASUALTY FIGURES FOR RAILROAD ACCIDENTS (AVERAGED OVER 1968, 1969, 1970)

Kind and Class of Accident	Number of Accidents	%	Number Killed	%	Number Injured	%
All accidents with casualties	22,955	100	2,294	100	23,097	100
Train accidents	459	2	185	8	1,031	4
Train service accidents	15,247	66	2,029	88	14,788	64
Grade crossing	3,398	15	1,353	59	3,420	15
Other	11,849	51	676	29	11,368	49
Nontrain	7,249	32	80	4	7,278	32

accounted for most of the casualties. Most injuries were received in getting on and off cars and in miscellaneous falls, with many also associated with coupling, uncoupling, and operating switches and hand brakes. Most deaths involved individuals being struck by trains. The statistics do not indicate to what extent the engineer was involved in these accidents.

The data for train accidents are more revealing of engineer-related causes. Table 2-2 shows yearly figures averaged over the period 1968-1970. The Office of Railroad Safety Bulletin includes a breakdown for employee negligence, which we see accounts for 27 percent of the damage, 11 percent of deaths and 38 percent of injuries. These percentages reflect an average of $20 million a year in damage, 21 deaths and 407 injuries.

TABLE 2-2. ANNUAL TOLL OF TRAIN ACCIDENTS (AVERAGED OVER 1968, 1969, 1970)

	Number of Accidents	%	Damage	%	Number Killed	%	Number Injured	%
Total train accidents	8,222	100	$122 M	100	185	100	1,031	100
Train accidents due to employee negligence	2,235	27	$ 20 M	16	21	11	407	38
Total collisions	1,764	100	$ 17 M	100	22	-	385	-
Collisions due to employee negligence	1,540	87	$ 14 M	84	-	-	-	-
Train accidents due to negligence in train handling	1,131	14	-	-	16	9	338	32

We cannot break out the engineer's contribution to these figures directly, but there are two ways in which the engineer's involvement can be estimated. First, errors by engineers frequently lead to train collisions; so the breakdown "collisions due to employee negligence" is likely to reflect a high degree of engineer involvement. This category accounts for 87 percent of all collisions and 84 percent of the damage done by collisions, some $14 million per year (Table 2-2). A separate analysis of human-caused collisions over roughly this same period showed the engineer to be at fault in 77 percent of them, yielding an estimate of over $10 million per year in damages attributable to engineer error in collision accidents.

A second approach to the engineer's involvement in train accidents was to go through the detailed causes of accidents and add up the casualty figures for those causes in which the engineer was most likely to be involved. The results (see Table 2-2) showed 14 percent due to negligence in train handling, accounting for a yearly average of 16 deaths and 338 injuries.

In the period 1968-1970, the most frequently occuring cause of train accidents that might have involved an engineer was absence of a man on or at the leading car being pushed (the engineer is partially responsible for seeing that this precaution is taken). The ten leading causes of accidents that might have involved engineers were as follows, in descending order of frequency:

- Absence of man on or at leading car being pushed
- Switch improperly set
- Running through switch
- Emergency or severe application of air brakes
- Failure of engineman to keep proper lookout
- Equipment fouling switch
- Excessive speed or failure to control in yard limits
- Other improper handling of locomotives and other cars
- Other improper handling in switching
- Attempted or acutal coupling at excessive speed

The Office of Safety data do not permit us to identify which causes led to the greatest damage, but an analysis of causes leading to casualties gives a somewhat different set of causes. Negligence leading to deaths involved, in descending order of frequency:

- Disregard of stop signal or board
- Excessive speed or failure to control in yard limits
- Absence of man on or at leading car being pushed
- Failure to flag
- Overrunning meeting point
- Disregard of restricting signal
- Switch improperly set
- Excessive speed on other than yard limits
- Failure of engineman to keep proper lookout

The leading causes of injuries were essentially the same but in different order. The first cause accounted for far more deaths (15) and injuries (497) than any of the others during the three years.

2.3.2.2 <u>Accident Reports</u> - An analysis was made of 30 collisions over the period March 1968 through May 1971 on which detailed accident reports were published. Table 2-3 summarizes the involvement of engineers in these accidents. The engineer was at fault in 23 (77 percent) of these accidents (generally not alone, but a significant or primary causative agent). In these accidents, he was going too fast in 74 percent and overran a stop signal in 61 percent. In 39 percent he was acting under false expectations.

Several other causes led to one or two accidents, and some of these can be roughly grouped as having elements in common. If we combine accidents involving loss of attention, we get a total of 13 or 56 percent of the engineer-caused collisions. This syndrome of inattention is generally compounded of several causes including fatigue, boredom, distractions, the soporific effects of the steady noise of the engine and rhythmic rocking of the cab, heat and stuffiness, and others in various combinations. In a

TABLE 2-3. ANALYSIS OF THIRTY COLLISIONS INVOLVING EMPLOYEE NEGLIGENCE 1968-1971

CAUSES	Number of Accidents	% of Total	% Engineer at Fault
Engineer at fault	23	77	100
Failed to observe speed restrictions	17	57	74
Failed to observe stop signal	14	47	61
Loss of attention (4 cases involved fatigue, alcohol, drugs)	6	20	26
Lack of attention	7	23	30
Acted under false expectations	9	30	39
Inexperience	1	-	-
Illness	1	-	-
Cut out safety device	1	-	-
Poor train handling	1	-	-
SPECIAL CIRCUMSTANCES			
Engineer alone	4	13	17
Unusual operating conditions	7	23	30
Poor radio communications	8	27	35

few, yet still too many, cases these factors were further aggravated by the effects of alcohol or drugs. Although the numbers are few, the vision of a 15,000 ton freight train roaring into a collision at 65 miles per hour, with the crew asleep in a drunken stupor, is indeed frightening. Moreover, conversations with many railroadmen have uncovered anecdotes that suggest that many engineers have experienced drowsiness on their runs and have dozed off at the controls, fortunately awakening almost immediately with no serious consequences. The potential of this syndrome to cause future accidents warrants attention more urgently than the accident numbers suggest.

Several other circumstances were hypothesized as contributing factors and checked against the data on the 30 collisions. No pattern emerged for time of day, weather conditions or obstructions to visibility. A few special circumstances are worthy of note, however. In 35 percent of the engineer-caused accidents some fault in radio communications was involved. Sometimes the equipment was at fault, but in several cases poor communications procedures established or strengthened false expectations on the part of the engineer. The National Transportation Safety Board has also noted this situation, and the FRA is presently taking corrective steps. In 30 percent of the engineer-caused accidents, some unusual condition existed, such as malfunctioning signals, repairs to tracks and the like, which caused a departure from routine operations. The engineer would proceed in the old routine against contrary signals in such circumstances. Finally, in four accidents, for one reason or another, the engineer was alone in the cab at the time of the accident. The numbers are small, but in view of the trend toward reducing crew size, the effect of being alone on the inattention syndrome should not be overlooked.

2.3.3 Task-Related Factors

2.3.3.1 General Approach and Progress - One way to estimate the hazards inherent in a job is to specify every task that is performed in doing the job and to rate each task for its potential to lead to an accident. Initial analyses of this kind for several railroad jobs were produced by SysteMed, Inc., for the FRA, but they were based on relatively little data. The present project is conducting an analysis of the engineer's job in five steps:

a. Review the relevant literature
b. Observe operations
c. Prepare a preliminary evaluation
d. Verify findings by observations and interviews
e. Report

To date, the first two steps have been performed and the third started. Train handling studies, rule books, operating manuals and other literature have been reviewed. Road foremen have been interviewed, and cab rides have been taken (on both freight and passenger operations) on four railroads. A contract has been let with McDonnell Douglas Electronics Company to perform the hazards analysis, and field trips to additional railroads to verify conclusions are planned.

The following observations of the potential contributions of the locomotive engineer to safety, then, are based on substantial, but incomplete, study and must be considered tentative.

2.3.3.2 Preliminary Tasks - Before he ever moves his locomotive, the engineer performs a number of preliminary tasks, classifiable as:

a. Signing in and receiving orders
b. Inspecting the locomotive
c. Testing air brakes

When the engineer signs in for a day's duty, he must check bulletins for special conditions, receive orders detailing what work is to be done, discuss this information with his crew, and check his watch for accuracy. The thoroughness with which he performs these tasks can have an effect on the subsequent safety of his work. A major factor in safe train handling is the anticipation of future events far enough in advance to permit appropriate control actions to be taken. The bulletins alert him to special conditions that he may expect, particularly those involving special speed restrictions, rerouting, work crews on the line, and the like. Between written and oral instructions, he will receive information on the nature and distribution of the load he must handle, the switching operations he must conduct, and the route over which he will move. The more capable and conscientious the engineer is at locating and assimilating all the relevant data, the more appropriate will be his subsequent decisions in handling his train. He increases the chances of a smooth operation by assuring himself that head-end crew members have the information they need. The accuracy of his watch is particularly critical to assure safe, timely meetings with other trains.

The engineer may increase the chances of an accident through failure to read or understand train orders. Often he receives additional train orders enroute, which he may have to read while distracted by other duties. Or he may have to copy them from a radio transmission, complicated by both radio and cab noise. There is always a chance, too, that he may forget some details in an order he has read. The engineer is not always at fault; orders may be erroneous; a crew member may fail to pass orders on to him; and the language of orders may be confusing or ambiguous.

Responsibility for inspection of the locomotive consist varies considerably within the industry. When it is assigned to the engineer, the thoroughness of the inspection is often left to his judgment. The safety-conscious engineer will not cut corners in this task but will check to assure that appropriate switch and valve settings have been made on all units, that sanders are working, that fuel and water are adequate, that there is no loose or dragging gear, no air or oil leakage, that hand brakes are released on trailing units, that the air compressor is working, that moisture has been drained from the main reservoir, and that lights, horn, bell, windshield wipers, etc. are working properly. He will assure that a timetable and flagging equipment are available. Accident reports do not assign poor initial inspection as a principal cause of accidents, but it is very likely a contributing cause, just as a thorough inspection has very likely prevented innumerable accidents from occurring.

Brake tests are required by law whenever a train is taken out on the road. The engineer must operate brakes and check his gauges to assure that no significant leakage exists in the compressed air system, check or supervise the checking of brake cylinder piston travel in his locomotives, conduct a test of train brakes, assure that each cylinder has been visually inspected, and make a running test of his full train. The engineer must be thorough in brake testing, for loss of brakes is claimed in many serious accidents, and subsequent investigation has sometimes uncovered defects that should have been detected in the brake tests. Impatience or inattention on the part of the engineer in this task can be a critical safety factor.

2.3.3.3 General Train Handling - The basic message of this entire section is that the engineer's skill in train handling is critical for safety. The complexities of the job have been detailed in Section 2.2. A continual requirement for safe train operation is the skill and judgment that the engineer applies to combining his knowledge of work requirements, rules and orders, power characteristics, length, weight and distribution of load, grade and curvature of track, and a multitude of environmental factors with the probable effects of applications of throttle, air brakes and dynamic brakes to select the control actions that will cause the train to move or stop as required. He must also take these control actions at the right time.

When the train is moving, the engineer is in control of potentially hazardous forces. When standing, the train is still a hazard as an obstruction, and the engineer must assure the taking of whatever precautions are required by the company rules to protect his train. So the engineer is vital to safety at all times. Even so, we can note several situations that involve special hazards.

2.3.3.4 Road Operations - Long hauls of heavy loads over steep grades, requiring frequent applications of brakes, may deplete the compressed air supply by drawing off air from the main reservoir faster than the compressors can replace it. Pressure maintaining valves and dynamic braking have significantly reduced this problem; however there is still enough old equipment in operation so that an engineer must be alert to the necessity to monitor his reservoir pressure, husband his air, and stop and set some pressure retainers if necessary.

Any high speed or downhill operation forces the engineer to think ahead and plan his strategy for stopping. On undulating territory he must be aware of, and in control of, the slack in his train. Under all conditions he must anticipate wayside signals, observe and understand them, and scrupulously obey their indications. Failure to observe a signal is basic to many serious collisions, as is failure to estimate speed and judge stopping point accurately.

Low speed operations can be hazardous, too, particularly if the engineer is distracted by a complex situation. Moving through a densely populated area, with numerous switches, crossovers and grade crossings as well as children playing on or near the tracks and vandals attacking the train, requires alertness, level-headedness and the knowledge of exactly what to do in an emergency.

2.3.3.5 Yard Operations - In determining safety, the slow speed characteristic of yard operations is offset by the complexity of switches and signals, and the greater number of people and other trains. The engineer must know his routing, observe the right signals and be alert for other crews and equipment at all times. Often he is moving in reverse, where it is virtually impossible for him to see where he is going; so he must know and absolutely comply with proper radio procedures, hand signals and operating rules.

Every coupling is a collision. It is safe only insofar as it is a controlled collision. Several serious collisions have occured in recent years at speeds not much over coupling speeds in which locomotive cabs were demolished and crew members killed or seriously injured. Thus yard operations also depend for safety on the skills of the engineer.

2.3.3.6 Unusual Conditions - Engineers, like all humans, are creatures of habit. Sometimes their habits will persist even when they have been informed of some unusual condition on their route. The accident annals contain many instances where an engineer has caused collision by "riding the yellow"...that is, failing to slow down for a yellow signal because it has regularly changed to green in the past. Or an engineer may fail to note a stop signal because it is always go at that point. In general, safety requires the engineer to be continually alert and ready to adjust to the unusual.

This last admonition is especially so in emergency situations. Not only must the engineer be alert, he must also be able to respond immediately and appropriately. This conditioning of appropriate emergency responses requires training and practice and is a particular weakness in the current status of railroad safety. Locomotive cab simulators are particularly valuable for this kind of training, but there are only two carriers currently using them in this country (see Section 5.0).

2.3.3.7 Attention - As we have noted in discussing accident statistics, loss of attention is insidious and frequent. It causes many accidents and probably has compounded the effects of accidents with other causes. If the engineer has too much to do at a given time, he can miss a wayside of cab signal because of distractions. If he doesn't have enough to do, again he is easily distracted, perhaps by another crew member, irrelevant occurences in the cab, or daydreaming. Fatigue may be involved not only resulting from time on duty but from failure to get adequate rest between trips, or disturbances of circadian rhythms by irregular schedules. Time of day may be a factor; there seems to be a particularly strong tendency towards drowsiness in the early morning hours, at sunrise or just before. Eating times and diet interact with these other factors, and drugs or alcohol can compound their effects. The engineer must stay alert, but much research is still needed to determine how to help him stay alert.

2.3.4 Workspace Factors

2.3.4.1 Cab Design - The design of workspace and layout of equipment can affect a worker's performance. Although there are numerous makes and models of diesel-electric freight locomotives in the U.S. fleet, their cabs are very much alike in basic design. The Human Factors Division at the Crane, Indiana, Naval Ammunition Depot is preparing a report in support of this project that will include scale drawings and photographs of a variety of cabs; so the description here will be limited to some typical features of common cabs.

A typical cab is about 10 feet wide, 7 feet long, 7 feet high in the center with a ceiling sloping to 5 1/2 feet in height on either side. The floor level is about 8 feet above the track, putting the engineer's eye level 11 to 12 feet above the track. The cab may be located in a variety of positions on the locomotive. On snubnosed models, the front windows may be only 7 feet back from the front of the unit. Other models have the cab farther back, and many switchers have the cab at the rear. The front windows are on the order of 1 1/2 feet wide by 2 feet high, one on each side of the front. Windows are similarly placed in the rear of the cab. Low-nosed models may have additional windows across the front.

The engineer's seat is located at the right-hand side of the cab, beside a large window about 3 feet wide and 2 feet high. The seat is always adjustable in height and in distance from the front of the cab; the seat also swivels. Because switching requires much movement in reverse, the seating must allow the engineer to sit back-to the large window, so that he can see forward and backward through the front and rear windows by turning his head to either side, or can lean backward out the large window for better visibility. This requirement also affects placement of the control and brake stands in yard and road freight locomotives.

On the left-hand side of the cab, one seat or two in tandem, are available for other cab occupants, with window arrangements similar to those on the right. An electrical panel occupies space on the rear wall in most cabs, and in other cabinets a water cooler and the like take up considerable floor space. Still the cab is roomy, and the operating personnel are not cramped.

Access to most freight locomotive cabs is through two doors, just over a foot in width and 4 feet in height. The left-hand door in in front of the fireman's position, contains the front window, and gives access to an exterior walkway along the side of the hood. The right-hand door is behind the engineer, contains his rear window, and gives access to an exterior walkway along the side of the engine. These very limited means of exit may contribute to the high proportion of in-cab casualties in accidents. Design of cab doors warrants further investigation.

Modern cabs are sound shielded; all cabs have heaters, and some (but very few) are air conditioned. Cabs are also vented, which constitutes a hazard in accidents in which smoke, flames and volatile gases are sucked into the cab. Even in weather extremes, it is often necessary to work with windows or doors open. The cab is thus an environment which can be comfortable but in which the comfort is frequently disturbed. The background noise level in cabs has been measured (Aurelius, 1971) at about 90 dB (A) at medium speeds, rising to 98 dB (A) when the horn was sounded, 105 dB (A) when the air brakes were applied. These levels are at about the upper limit of those allowable by the Walsh-Healy Act.

There is considerable lateral sway when the cab is in motion, punctuated by jolts during sudden stops, starts, or slack run-in. The crew is also subjected to a variety of vibrations, many in the range 1 to 10 Hz, least tolerable for humans.

What the net effect of this environment is on the engineer's body and how it affects his ability to perform safely are subjects of research being conducted in this project (see Section 3.0). How the effects of vibration, jolting, noise, and frequent changes in temperature may combine to induce fatigue or longer-term chronic difficulties is not known and will take considerable research to determine.

2.3.4.2 Cab Hazards - Just as safety of the train may be affected by the influence of cab design factors on the engineer's performance of his job, the safety of the crew itself is directly related to cab design. Recently, there have been a number of slow-speed collisions in which the rear car (generally the caboose) of one train rose from its wheels on impact, slid across the heavy underframe of the colliding locomotive, and crushed the cab, killing or badly maiming the occupants. In a sample of 30 collisions occuring in the period 1968 to early 1971, the cab was demolished in 15 of the accidents (50 percent). Concerned over this, the industry and the government have formed an *ad hoc* Locomotive Control Compartment Committee to investigate means for making the cab a safer working environment. This TSC project provides human factors support to the committee, including consulting and the aforementioned Crane NAD study of cab designs.

The cab is a particularly hazardous spot in collisions. In the 30 accidents mentioned above, a total of 114 persons were in lead cabs at the time of the accidents. Twenty-two of these people jumped from the train shortly before impact; 92 remained in the cab. One of those who jumped was killed, 16 were injured, and 5 were uninjured, a 95 percent survival rate. Of those who did not jump, 39 were killed, 14 injured and 39 uninjured - a 58 percent survival rate. Jumping from a moving train entails many risks that could not be evaluated from the data (related to time factors, speed of train, and trackside conditions). In spite of these risks there was a remarkable survival rate among those who jumped in the cases reviewed here; the cab was certainly not a safe spot.

Aside from collisions, how safe is the cab? Some data are available on injuries received by crew members and caused by faulty locomotives from June 1965 to June 1970. No deaths were reported. Of 530 injuries reported, one quarter of them were due to cab fixtures, 73 due to doors and windows, 63 due to seats. Slipping or tripping on floors, steps and passageways accounted for 60 more. Fires and shocks from electrical equipment caused 93 injuries. It seems from the available data that, given good maintenance, the cab is a reasonably safe working place, except in collisions. More detailed data are now being gathered by the FRA, and this project's investigation of cab safety will continue.

2.3.4.3 Workspace Layout and Equipment Design - Compared to an aircraft cockpit, there are relatively few controls and displays for the locomotive engineer to operate and monitor. Control handles are typically large and generally easy to reach and operate. Instruments are also large and easy to read. However, the large handles are hazards to the crewmen should they fall against them, and there are numerous other protruberances and sharp edges that merit consideration for redesign. Collectively, the controls and displays involve some dangers worthy of note.

Perhaps the outstanding characteristic of workspace layout in locomotive cabs is the lack of standardization. In the past, each manufacturer has had an individual design of the control stand and arrangement of the instruments, and over the years, some manufacturers have introduced one or more completely redesigned control stands. Beyond this, individual carriers often specify design modifications and install a variety of accessory devices. There has been a trend toward standardization in recent years, culminating in one standard control stand design being approved by the Association of American Railroads (AAR). Most equipment coming into the inventory in 1972 and later will have the AAR control stand. However, locomotives last indefinitely, and in the near future the engineer of most carriers will continue to have to know a variety of layouts, even within a single power consist.

One particularly hazardous design feature in some locomotive models has been noted. This is the use of the throttle handle as the control for both power and dynamic braking (see Section 2.2). Although it is difficult to prove, investigators have been fairly certain in the case of a few serious derailments that the engineer was applying full power in the mistaken notion that he was applying dynamic brakes. Position of the selector lever, an indication in a small display window, or the behavior of the train should tell the engineer what mode he is in, but in a complex emergency this feedback may come too late, when the train is already out of control.

The AAR control stand was designed to make such an error impossible, assigning power and dynamic braking to different control handles that move in opposite directions. One manufacturer now sells a kit that improves his older stand by making the selector position more obvious, displaying mode in a larger window, and substituting a new load meter with both power and dynamic braking zones. Nevertheless, these improvements will be slow in entering the fleet; many of the older control stands will be in use for years to come.

2.3.5 Summary of Implications for Safety

Annually crew negligence causes some 2000 train accidents, at a cost of $20 million, 20 lives and 400 injuries. About half of these seem to be directly attributable to the engineer, whose most costly error is disobedience of speed restrictions or stop signals. The causes of such negligence are not clearcut, but a significant factor in many accidents is loss or lack of attention for a variety of reasons. Other identifiable factors include poor radio communications and unusual operational conditions that may lead to false expectations. The significance of the engineer's being alone in the cab warrants further investigation.

It should be obvious from this analysis that the critical kinds of information needed to pinpoint and correct human-related causes of accidents are not available in the published statistical summaries. The FRA is exploring ways for improving accident investigation and reporting, and TSC is providing human factors support to that effort. A detailed account of this activity is provided in Section 4.0.

Detailed task analysis and hazard evaluation is still in progress. Tentative findings suggest that the potential for accidents is present in almost every task of the engineer. Safety is related not so much to specific tasks as to how well the engineer performs the tasks. Negligence in any one task may not be dangerous, but the combined effects of negligence in several tasks can cause a serious accident. Whether moving or standing still, the train is a potential hazard. The higher the speed, the more complex the load, and the more variable the road, the more factors an engineer must take into account and the more lead time is needed for safe train-handling decisions.

As a workplace, the cab of a well maintained locomotive is not an excessively dangerous spot, with one exception. The cab and its occupants suffer severe damage in collisions even at slow speeds. Several efforts are under way to alleviate this situation.

Improvement of the current layout of cabs and cab equipment presents several human engineering problems. Many protruberances and sharp edges should be better protected. Improvement of seating, sound shielding, heating and ventilation is desirable. More study of vibrations is needed. Major revision and standardization of the design and arrangement of displays and controls is desirable; there are hopeful, although slow, trends in that direction.

2.4 REQUIREMENTS FOR PROFICIENCY

2.4.1 Introduction

From the nature of the job and its accident potential, as described in Sections 2.2 and 2.3, we can deduce the qualities in a person that are necessary for him to be a good locomotive engineer. Three classes of characteristics are considered: physical attributes, psychological attributes, and job knowledge and skills.

A knowledge of the physical attributes required for safe train handling is basic to the establishment of physical fitness standards and the definition of medical examinations for their determination. These standards are currently being studied; the status of this work is reported in Section 3.0.

Understanding the psychological qualities that underlie safe train handling can have several results. For general mental health, a psychiatric screening could be added to required medical examinations. Aptitude testing is another potential development to aid in the initial selection of candidates who are most likely to become successful engineers. More research on psychiatric factors, aptitudes and motivations is require before recommendations for standards can be made.

Job knowledge and skills are acquired through training and experiments. Training quality and job proficiency can evaluated in different ways. Training can be specified and checked in terms of curricula, facilities, and instructor staff. However, the real criterion of training effectiveness is the job performance of the trainee. Proficiency testing is thus a basic necessity to evaluate both training and on-the-job capability. Research is needed in this area also to determine first which skills make a good engineer and then to develop efficient, reliable ways of measuring these skills.

2.4.2 Physical Attributes

2.4.2.1 General Health - As in any job, illness of any kind can cause deterioration of the engineer's performance and thus compromise the safety of his train. The hazards to train safety are obvious with regard to such dramatic events as a sudden heart attack, stroke, epileptic seizure, or diabetic coma. Just as obviously, medical examinations for engineers must include whatever means are feasible to detect the possibility of such occurences and to screen out persons susceptible to them. A more difficult area to control is the type of illness that slowly fatigues a person, distracts him from giving full attention to his job, clouds his judgment and perhaps causes him to care less about what happens to him and his train. Medical examiniations can uncover chronic illnesses that may have such side effects (headaches, pains, chills, nausea, etc.), but regulations can not cover those situations where the employee does not feel well.

Regulations must also provide for professional medical control of medication. Any medicine is a drug and can have side effects that compromise safety. Many simple nonprescription medicines, such as cold remedies, can induce drowsiness. Sometimes combinations of medicines can have effects not generally attributed to any of the individual medicines taken alone. Self-dosing for minor ailments is hazardous to safe train operation and must be discouraged in any regulatory program.

2.4.2.2 Strength and Stamina - The engineer's job is basically sedentary. Although he must frequently manipulate a number of levers, they do not require any great degree of physical exertion. On rare occasions, circumstances may require the engineer to leave the cab to operate a switch; however, this activity is not a part of his normal routine.

Hours-of-work regulations already exist, assuring the engineer a non-fatiguing schedule with regard to consecutive hours on the job and rest between jobs. However, there are no controls at present for regularity of schedules. An engineer on call may frequently alternate between day and night duty, thus interfering with his circadian rhythms, which can lead to irritability and tired feelings. More research is needed in this area, as well as on the effects of the nature and regularity of his meals on his job performance.

Although sedentary, and calling for little physical exertion, the engineer's job is not free from stress. Because of the time required to stop a train, the engineer must be continually alert and prepared to react to emergencies. He must also be planning ahead at all times for scheduled stops and regularly observing signals for both scheduled and unscheduled requirements to control his train's speed. The engineer works in an environment characterized by a generally high noise level and punctuated by even louder noises (brake exhaust, horn). He is subject to a variety of vibrations, and his seat is not well designed for support and comfort. The temperature and humidity of his working environment vary considerably, both seasonally and on a single run. Although the engineer is in a protected cab, and may sometimes be provided with air conditioning, he must often work with an open window, particularly in backing up and switching, and he is therefore regularly exposed to the extremes of the weather. Many cabs are drafty in cold weather; with a heater on and with windows alternatly open and shut and engineer may have to adjust to frequent changes from hot to cold. The net effects of these stresses on the engineer's body, particularly as a function of time, is not known. To gain this kind of knowledge, experiments are being conducted in which a number of physiological measures are taken on an engineer at work in the cab. This work is reported on in Section 3.0.

2.4.2.3 Vision and Hearing - Engineers must possess normal (or correctable to normal) vision and hearing to perform their jobs safely. They must be able to read instruments, read instructions (often in fine print), and read the contents of wayside signs. This reading must often be done under poor, and variable, illumination, particularly at night. On a great many railroads, the block signal aspects are color coded, as are many cab signals; so normal color vision is a general requirement. Peripheral vision requirements are less well defined; picking up distant signals and observing the condition of passing trains can be affected by limitations of the visual field, but whether this factor is critical is not known. Depth perception is useful in stopping and coupling, but such cues as motion parallax and superposition probably can more than compensate for any loss of binocular stereopsis.

Normal hearing (or normal aided hearing) is necessary for the engineer to receive spoken or shouted messages from his crew, to understand radio messages, and to detect and distinguish audible alarms and warnings in a very noisy environment. The possibility that continued exposure to cab noise over the years may cause critical hearing loss needs to be explored.

2.4.2.4 Summary - In general, normal, rather than exceptional physical fitness seems to be required in the engineer's job. His work is basically sedentary in a protective environment. However, ther are stresses and tensions associated with his work whose net effect is not known. (Research is under way in this area, as reported in Section 3.0).

It is possible to combine current knowledge of the engineer's job with the experience gained in setting physical fitness standards in other areas (aviation, trucking) to generate an initial set of physical fitness standards and medical examination requirements for engineers. This effort is underway, not only for the engineer but for all railroad employees directly involved with train operations. Standards have been drafted and are currently under evaluation by medical experts. This effort is reported in detail in Section 3.0.

2.4.3 Psychological Attributes

2.4.3.1 General Mental Health - Although general mental health is as essential to safe train operation as is physical health, regulatory and screening techniques are less standardized in this area, which is not included in our initial fitness standards. Research and development of standards are highly desirable here.

Neuroses, in general, need not be disqualifying factors. They should be detected and under medical treatment, however, and should be checked often enough to assure that they do not develop to proportions that might interfere with safe train operation. For example, free-floating anxiety to a certain extent might be tolerable in an engineer; hysteria with associated functional paralysis or blindness would obviously be intolerable. The incidence of neuroses is very high in our population and therefore highly likely among engineers. Only a periodic psychiatric check-up can guard against neurotic conditions becoming hazards.

Active psychoses, on the other hand, are always a threat. Since the patient is in some way divorced from reality, a psychotic engineer cannot be counted on to exercise the sound judgment in train management so essential to safety. A study conducted in England (Ref. 3) showed a high incidence of psychiatric problems among a group of 23 engineers who had overrun stop signals. The incidence of such problems in this group was compared with that in a randomly selected control group of 27 engineers. There was no significant difference between these groups in physical health nor in history of accidents, injuries or illness. However, eight of the delinquent engineers complained of psychiatric symptoms, as compared to one in the control group, and nine had recurrent psychosomatic symptoms causing a break from work, as compared to three in the control group.

Extremes of depression and euphoria are rather easily detected, as are the bizarre manifestations of schizophrenia. However, early symptoms of these disabilities and even advanced paranoid conditions are not as evident to the layman. The question of regulated psychiatric evaluation of engineers deserves serious consideration.

Alcoholism and drug addiction are potential hazards to railroad operations. In the nine-year period 1962-1971, six serious railroad accidents occurred in which the influence of alcohol on the head-end crew was a principal or a contributing factor, and it has been suspected in others. These accidents caused 11 deaths, 361 injuries, and over three-million dollars in damage to railroad property. Because of these incidents, regulations controlling alcohol are likely to be forthcoming soon. With a growing drug problem in the population, it is likely that it will also increase in the engineer group. Although commercial carriers all forbid the use of alcohol and drugs, Federal regulation may be required to assure control.

There is virtually no information available on the effects of drug usage on train handling. It is presently hypothesized that although alcohol may slow down an engineer's reactions and deteriorate his motor skills, the greatest threat is its effects on his judgment as to what constitutes safe train management. Controlled studies of the effects of alcohol and drugs on all train-handling skills would be aided by the use of a realistic locomotive cab simulator. The FRA is studying the advisability of such an acquisition (see Section 5.0); if such a facility is established, drug studies will be considered as a part of its program.

2.4.3.2 Aptitudes - Evaluation of the basic aptitudes underlying train-handling skills can increase our understanding of what it takes to be a good engineer. Aptitude screening is a particularly valuable tool in employee selection and placement, since early identification of those who cannot succeed as engineers can effect great savings in training costs. The relationship of aptitude screening to safety is in the elimination of potentially unsafe persons before they ever control a locomotive.

Aptitude study, moreover, is a basic preliminary to proficiency evaluation and is thus worthy of consideration as a part of the process of developing proficiency measurements. The aptitudes that will be considered here are: language, symbolic data operations, perception and memory, decision making and motor skills.

Train handling is not basically a verbal activity, and language capability should not be critical to the engineer's job. However, it very likely is fairly critical because of the considerable amount of written material an engineer must take into account in making operational decision. Just the basic code of operating rules and timetable instructions that he must memorize and conform to, require verbal skills: these are overlain with bulletins, orders and oral commands. This situation might be somewhat alleviated by standardizing the provisions, minimizing the material to be learned, and simplifying the language. The desirability of such an effort as a factor in railroad safety has been stressed by the National Transportation Safety Board (1972). In the area of training there has been considerable success in developing manuals clarifying operating rules for persons relatively low in language skills. The Santa Fe Railroad is exploring the application of the same principles to the wording of the rules. Our TSC program will include a study of the clarity of rules in the near future. The engineer must also have normal skill in issuing verbal orders to other crewmen and in writing intelligible reports.

Symbolic data operations are a more fundamental part of the engineer's job than is generally realized. He must take data from orders, tables, manuals and charts and manipulate them mentally in determining the probable behavior of his train. In particular, he must integrate weights, weight distribution, power factors, braking factors, topology and time factors, understanding the mechanical and electrical principles that are involved, in order to time and gauge his control actions. Although the engineer may not be consciously aware of this computational activity, his ability to take all factors into account in his work is a significant determinant of his skill.

Perceptual skills and memory are vital to safe train management. Basic visual and auditory capabilities have been mentioned. Pattern perception is required for interpretation of wayside signals; even the color-coded signals generally include position coding too. Auditory discrimination is needed to some degree for recognition of audible alarms. General spatial and temporal perception are of particular importance. The engineer's ability to picture his train spread over varying grades and curves, to know where the light and heavy sections are, as well as to envision future train location, is a key element in determining his proficiency. Perceptual speed is required to permit timely control decisions to be made.

An engineer must have a long-term memory span, including verbal memory for rules and instructions and visual memory for the detailed characteristics of the route. An engineer must commit to memory every grade, curve, crossing, siding, signal, sign, landmark and the like on a route before he is considered proficient on that route. Memory of the principles of operation of power and braking systems is another requirement. Short-term memory is needed for a specific train's characteristics, current orders and the like.

Decision making is unquestionably the most critical function that an engineer performs. The aptitudes needed include the ability to determine a need for a decision from the perceived situation, to retrieve from memory the data relevant to the need, to hypothesize alternative solutions to the problem, to integrate perceived and memorized data into predictions of train behavior, to select the most appropriate solution and to intiate the required action. The engineer must continually monitor what is occurring and anticipate what is going to happen. Train safety depends upon his ability to anticipate, determine and initiate control actions early enough to achieve the desired control at the time required.

In view of the extremely slow and complex response of a train to power and brake changes, this ability to foresee, analyze, calculate and act appropriately and in time is the real hallmark of a good engineer.

Unlike automobile and airplane control, train handling does not require a high degree of motor skills. Reaction times are seldom critical; occasionally an emergency will require a quick brake application, but the difference of a few tenths of a second in responding is lost in the minutes it takes for the train to respond. Eye-hand coordination is required mainly in making measured air-brake pressure reductions, releasing the application as the pressure gauge needle approaches the desired value. Most control applications are in discrete steps, both with throttle and brakes; there are no continuous tracking tasks (like steering an automobile). There is often a requirement to perform several tasks at once for short periods (such as adjust speed, operate sanders, sound horn and respond to alertor), but even those situations require more skill in analysis, judgment and decision making then in motor coordination.

2.4.3.3 Inter-personal Relationships - Personality factors have not been considered to date in this project. It is too early to estimate whether measurable characteristics of personality might correlate with skill in train operation. It is desirable that the engineer be able to get along with the crew, have his orders obeyed, be alert, be able to respond effectively and calmly in emergencies, and be able to concentrate amid noise and distractions. Considerable research is required, however, to identify appropriate measures for valid and reliable selection of engineers on a personality basis.

2.4.3.4 Motivation - Study of individual railroad accidents frequently raises, and fails to answer, the question: "Why did the crew ignore the information or signals given them?" What moves a person to do what he does; what makes him want to do what he knows is best sometimes and not care at other times? This area of motivation is not very well understood. However, we can identify and examine several key factors, such as reward and punishment, morale, character and quality of supervision.

Psychologists of the conditioning school have created a vast literature on the efficacy of rewards and punishment in motivating behavior. The interactions are too complex to review here, but in many instances reward has been more effective than punishment in conditioning desired behavior. However, railroad safety is provided for primarily through punishment-obey the rules and nothing much happens; disobey the rules and you're punished. On the other hand, it is not a simple task to establish a workable program for safety based on rewards. The unions maintain a continual effort to provide material rewards for their members, but their rewards are for service rather than safety. Pay increases and promotion are the ultimate rewards for proficiency and a good safety record, but they generally lack three factors necessary for continued motivational effectiveness: certainty, immediacy and fairness. Only a few engineers can rise to the top; it takes years to achieve this success, and factors other than good job performance often are involved. So when a decision involving safety must be made, there is little internal force related to reward or punishment helping determine what the engineer will do. Career ladders with frequent rewards, short-term goals which one can be working toward at all times, have proved to be effective motivating forces in other industries and might be worthy of investigation by the railroads.

It is well known that when people are dissatisfied with their job situation, the quality of their job performance often deteriorates. The man with a grievance is a little less likely to exert himself to obey all the company's rules. In the area of morale, again the unions are an active force and supply an approved channel for resolving grievances, but again the process is slow and may not forestall a slip in job performance. The industry apparently does not have any continuing program for assessment and improvement of morale.

In other industries it has been noted that when general morale is low, the motivational effect varies considerably. Some people will do their best in spite of low morale; others will let morale influence their job behavior. We will use the term "character" to represent this built-in motivational force. Organizations have long appealed to character as a means of motivation, particularly with regard to loyalty. It has been pointed out to the writer by one young engineer that recent years have seen a tremendous change in national concepts of loyalty which is bound to have its effect on the railroads. The generation now providing the new engineers to the industry must be appealed to on a rational and personal basis; neither loyalty to the company nor loyalty to a union will have the motivational force that they had for earlier generations. This change of motivational patterns is critical for the industry and deserving of study.

A primary determinant of the efforts an engineer will make for safety is the nature and quality of the supervision he receives. Far too often, laxity in enforcement of rules has been a contributing cause of serious accidents. Fear of punishment need not be the sole motivational force resulting from supervision. A trained supervisor backed by a well-structured company policy can help the engineer understand and feel the desirability of safe practices so that his reflexive responses are the safe ones because he wants to perform this way rather than because he is afraid not to. Therefore, the selection and training of supervisors can have a significant effect on the safety of a carrier's operations.

In summary, safety in railroad operations can be promoted through the motivation and morale of engineers by a well-planned set of frequent, certain and fair rewards and penalties, through study and appeal to loyalties, and through selection and training of supervisors. The role of the Federal Government in this process is not easily determined; however, Federally-sponsored research to increase our understanding of the role of motivation in railroad safety is a first step worthy of consideration.

2.4.3.5 Summary - Mental health of engineers is important for railroad safety. Initial standards are being drafted for alcohol control, and it is recommended that consideration be given to study and development of standardized psychiatric checkups.

The most critical aptitude for a good engineer is decision making, followed by perception and memory, symbolic data operations and language ability. Motor skills are not particularly critical, and language requirements can be lessened by simplification of written regulatory material. Personality traits and motivational factors are less well-defined, and considerable research is needed to determine the feasibility of their use in engineer selection and supervision.

2.4.4 Job Knowledge and Skills

2.4.4.1 General - It is self-evident that skill in train handling must be developed and maintained to assure safety of operations. The development of skills is achieved through initial training. Maintenance of skills is achieved through practice and refresher training. Management of these processes requires techniques for the evaluation of skill levels, or proficiency measurement.

2.4.4.2 Training Requirements - Of all the human factors problem areas related to the locomotive engineer, requirements for job knowledge and skills is probably the best understood and most thoroughly structured. This knowledge is well evidenced in the training requirements set up by most carriers. Job knowledge requirements include:

a. Engineer's duties and responsibilities

b. Company rules for operation and safety, including signal systems

c. Use of timetables, bulletins, orders, etc.

d. Locomotive design and operation

e. Air brake design and operation

f. Train handling theory

g. Basic electrical and mechanical theory

h. Details of assigned routes

Job skill requirements include:

a. Inspection of locomotive

b. Starting engine

c. Starting and stopping, on level grades, curves

d. Accelerating, use of throttle

e. Braking, use of air and dynamic brakes

f. Coupling, uncoupling

g. Responding to emergencies

2.4.4.3 Training Methods - The railroad industry lags far behind aviation (for example) in the formalization of training based on sound educational theory and methodology. Traditionally engineers have been trained as apprentices through on-the-job observation and then practice under the supervision of the assigned engineer, and this is still basic for most carriers.

However, there are hopeful trends. Many lines have come to realize that a good engineer is not necessarily a good instructor and have set up programs that put apprentices to work under engineers who are selected as good teachers. Special instruction and facilities have been established for teaching and reviewing specific skills, particularly air brake techniques, although their use is sometimes limited by poor educational practices. A few carriers have established engineer schools, with skilled instructors, a comprehensive integrated curriculum, and numerous training aids. Two such courses include a locomotive cab simulator, in which the student can obtain realistic instruction and practice, both in routine and emergency operations, without the costs and dangers inherent in on-the-job training. Simulators pay off both in accelerating the qualification of engineers and in imparting some skills they might not learn and practice in a lifetime of road operations. Programmed instruction in the form of self-training manuals has been adopted effectively by some carriers.

The trends are hopeful, but progress is necessarily slow. Study, adaptation and evaluation of new training methods and devices are expensive and time-consuming processes. Federally sponsored research and development in training methods would be a valuable service to the industry. Federal regulation of the type and quality of training basic to qualification of engineers must be considered as a step toward increasing operational safety.

2.4.4.4 Proficiency Measurement - Evaluation and control of training for safety requires some reliable means of determining status and needs with regard to job knowledge and skills. All carriers require qualifying examinations of engineers on operating rules. Some require refresher training periodically; others make it available but optional. Examination may be by written test, oral test or both. Job performance skills are generally evaluated through on-the-job observation by road foremen or similar supervisors; all carriers have a program of continual spot-checking. Although these examiners are skilled and dedicated specialists, they vary in their techniques and criteria. In general, basic standards or proficiency necessary for safety are not well defined and the methods or evaluation are even less standardized; there is no guarantee of a basic set of skills among all qualified engineers.

A research program that would be of great benefit to the industry would be the development of standard job-performance criteria for engineers and standardized tests for evaluation of proficiency. Such a program would combine current understanding of the job knowledge and skills basic to safety, would devise tests that could be administered and scored uniformly on all roads, and would determine the criterion scores desirable for engineer qualification and requalification. Such tests could be used to evaluate training programs and to check the proficiency of operating engineers. A realistic cab simulator would be a highly desirable research tool for this project. Should the FRA acquire a research simulator, proficiency studies would be a priority program for the facility (see Section 5.0).

2.4.4.5 Summary - The job knowledge and skills necessary for safe train handling are relatively well formulated. Methods for teaching and maintaining these skills vary considerably in the industry, and although hopeful signs of progress are evident, the progress is slow. Standardized proficiency tests of engineering skill are potentially of great value to the industry both for evaluation of training and evaluation of job proficiency. Recommended government research includes:

a. A survey of current training;

b. Development of training standards;

c. Development of standardized proficiency tests.

3.0 PHYSICAL STANDARDS FOR RAILROAD EMPLOYEES

3.1 DEVELOPMENT OF REGULATIONS

3.1.1 Introduction

In any transportation system the level of performance of the operating personnel directly affects the safety of the system. Physical disabilities and chronic or episodic illness can degrade performance and so endanger the public, the operating personnel, and both public and railroad property. To reduce this hazard the Federal Government has developed and adopted standards for health and physical conditions for the personnel of a number of transportation industries.

There are standards for flight personnel under the jurisdiction of the Federal Aviation Administration, for truck and bus drivers administered by the Bureau of Motor Carrier Safety, National Highway Traffic Safety Administration, and standards for officers and crew of Coast Guard vessels administered by the U. S. Coast Guard. At present, however, there is no set of Federal physical qualifications covering the railroad industry. Each railroad has developed, has promulgated and enforces its own physical standard regulations.

The Federal Railroad Administration, as part of its efforts at providing uniform safety-related standards and regulations for the railroad industry, is investigating the advisability of developing physical qualifications for railroad operating personnel. To support this effort the Transportation Systems Center is assembling and evaluating a body of regulatory material to be considered for inclusion in the proposed standards.

3.1.2 Development of Standards

The development of these standards involves the following steps:

a. Consideration of the duties and nature of the positions covered with regard to the effect of the physical condition of the employee on safety.

b. Study of existing regulations promulgated by Federal agencies covering other transportation industries.

c. Consideration of the currently available diagnostic tools and techniques necessary to make enforcement of any set of regulations possible.

d. Research into the development of techniques for evaluating the physiological and behavioral stresses inherent in the performance of railroad jobs.

During FY'72 the Transportation Systems Center, with the aid of Mr. Fred Holland (Consultant to the Department of Transportation), has studied the various operating personnel positions as they generally exist in the railroad industry. The study was performed through the following steps:

a. The positions to be covered by the regulations were identified. The guiding principle was that, to be covered, the position had to be one where impaired performance could directly affect safety. On the basis of this principle, the following positions are under consideration for coverage in the proposed regulations:

   1. <u>Locomotive Engineer</u>, as well as positions such as firemen or hostler, where individuals so employed are likely to perform similar critical functions.

   2. <u>Conductor</u>, as well as positions such as assistant conductor, yard conductor, engine foreman, or foot board yard master, where the individuals so employed are likely to perform similar critical functions.

   3. <u>Trainman</u>, or positions such as brakeman, flagman, baggage handler, or ticket collector, where the individuals are likely to perform similar critical functions.

4. Track Motor Operator or operator of other track equipment.

5. Chief Train Dispatcher or dispatcher.

6. Train Director, Tower Operator or operator.

7. Leverman

8. Bridge Tender

b. The selected positions were described in terms of the general duties associated with them, the specific duties particularly hazardous to safety, the job environment in terms of its interaction with the physical condition of the job holder, and the combined effect of these factors on safety.

c. These positions were grouped with regard to extent to which they were critical to safety and with regard to the ways in which the special requirements of these positions might place special physical requirements on the individuals holding them.

d. A detailed treatment of this material was issued as a memorandum entitled: "Task Analysis of Selected Railroad Operating Positions for the Purpose of Applying Medical Standards", prepared by Mr. Fred Holland. It is included in this report as an Appendix. This document was prepared for the use of physicians in judging the efficiency of applying particular health standards to the positions to be covered. It is purely descriptive and it is not intended nor should it be used to define or codify the duties associated with any of the listed job titles.

e. In order to obtain a better perspective on the form of similar regulations used by the FAA, BMCS and USCG, their standards were reviewed and compiled into a comprehensive document. In the compilation, the regulations are categorized with regard to the physiological system or systems they cover and further categorized into the particular disorder, condition, or pathology involved.

The major catagories consist of standards relating to:

1. Cardiovascular system
2. Respiratory system
3. Visual system
4. Auditory system
5. Bones and joints
6. Blood and blood forming organs
7. Gastrointestinal and genitourinary system
8. Behavior and nervous system
9. Miscellaneous conditions

While this compilation originally consisted only of Federal regulations, it was expanded to include the set of regulations developed by the AAR. Further, when available, the parallel regulations of foreign national railway systems, such as those operated in Great Britain and Japan, will be added. It must be emphasized that it is not expected that all of the compiled regualtions or even a large majority of them will be proposed for the U.S. railway systems as written, but rather, where appropriate they will serve as reference models for our development of railway regulations.

3.1.3 Medical Evaluation

To develop and select the regulations will require considerable aid from physicians familiar with regulatory problems, industrial medicine and diagnostics. A major source of support in this area has come from the Medical Standards Division of the Federal

Aviation Administration. Dr. Gordon V. Norwood, Division Chief, and Dr. Jon L. Jordan of his staff have provided assistance in the following areas: evaluatory review of regulations listed in the compilation, discussion of the pros and cons of various enforcement strategies and suggestions for making the "Task Analysis of Selected Railroad Operating Positions for the Purpose of Applying Medical Standards" more useful to its intended users.

The Lahey Clinic Foundation of Boston is expected to provide another major source of support in this effort. Under contract to TSC they will provide aid in developing regulations and reviewing the efficacy of developed regulations.

Physicians who have a familiarity and interest in the problems of industrial medicine and a professional specialization in one or more of the nine catagories for standards listed above, and are willing to aid in reviewing the regulations, will be selected from among individuals nominated by the FAA, Lahey Clinic Foundation, the various concerned labor unions and the AAR. They will be asked to review those regulations in their area of specialization with regard to the following:

a. Is the condition covered by the regulation, when applied to each job category, detrimental to railway safety?

b. Can the physical condition covered by the regulation be reliably and objectively diagnosed?

c. Does the diagnosis require unusually elaborate facilities and/or extraordinary training?

d. In the opinion of the respondent, is the regulation clearly and unequivocally written?

The clinic will aid in evaluating the physicians' responses. The clinic will also suggest and evaluate diagnostic tools, procedures and techniques to support the implementation of the regulations.

3.2 IN-CAB STRESS MONITORING SYSTEM

3.2.1 Introduction

While the above efforts are underway and expected to result in preliminary rules for FRA review by the end of September 1972, TSC is also developing more advanced techniques for evaluating both degraded performance and the causes of such degraded performance in operating personnel.

In order to determine the behavioral and physiological stresses associated with the duties performed by the engineer, a stress measurement system is being developed under this program. The system involves making on-line measurements of the engineer and the engine and correlating them with observations of the exterior operating environment.

3.2.2 System Description

The system described below is being developed by TSC. Dr. John Jankovich of the Research Staff of the Crane Naval Ammunition Depot is aiding in the gathering of data and providing liaison with the participating personnel of the Crane Railroad.

In its initial form the system is composed of sensors, signal conditioners, a multichannel data recorder, and miscellaneous support equipment which can be installed and operated in a railroad engine cab with a minimum of interference with the duties of the crew. This system can be better understood by describing the information which is recorded. This information falls into three categories:

a. Electrophysiological Measurements

b. Engine and Train Measurements

c. Other Measurements

The following sections describe in detail those measurements.

3.2.3 Electrophysiological Measurements

The first category includes electrophysiological signals used as indicants of behavioral state.

a. Electro-cortical potentials from the region of the left occipital cortex. These recordings or electroencephalograms are useful in determining whether the subject is attending to visual information in the environment or not. Periods of inattention are associated with alpha rhythm, a regular sinusoidal wave form with a frequency of from 8-13 Hz and an amplitude approximately 50 μv. The alpha rhythm occurs in well defined bursts during periods of awakened realization, inattention or daydreaming. Figure 3-1 is an electroencephalogram illustrating an alpha burst recorded from an engineer while he was operating his engine.

b. Electromuscular potentials taken from the biceps or triceps muscles. These electromyograms indicate by their amplitude and duration, the amount of energy expended in the arm recorded from (relative to the resting state). The frequency of occurence of the signals is an indicant of the frequency of arm movement.

c. Electromuscular recording from the cervical muscles. These recordings or electromyograms reveal the muscular activity used in supporting the engineer's head, and have been used as an indicant of fatigue.

d. Electromuscular recordings from the heart. These recordings or electrocardiograms provide information bearing on the changes in the engineer's emotional state and may be useful in determining the occurance of fatigue. In general, changes in emotional state are reflected in changes in heart beat rate, although the particular beat rate change may be idiosyncratic to the individual. Further, it has been suggested that decreases in heart beat rate variability reflect the onset of fatigue.

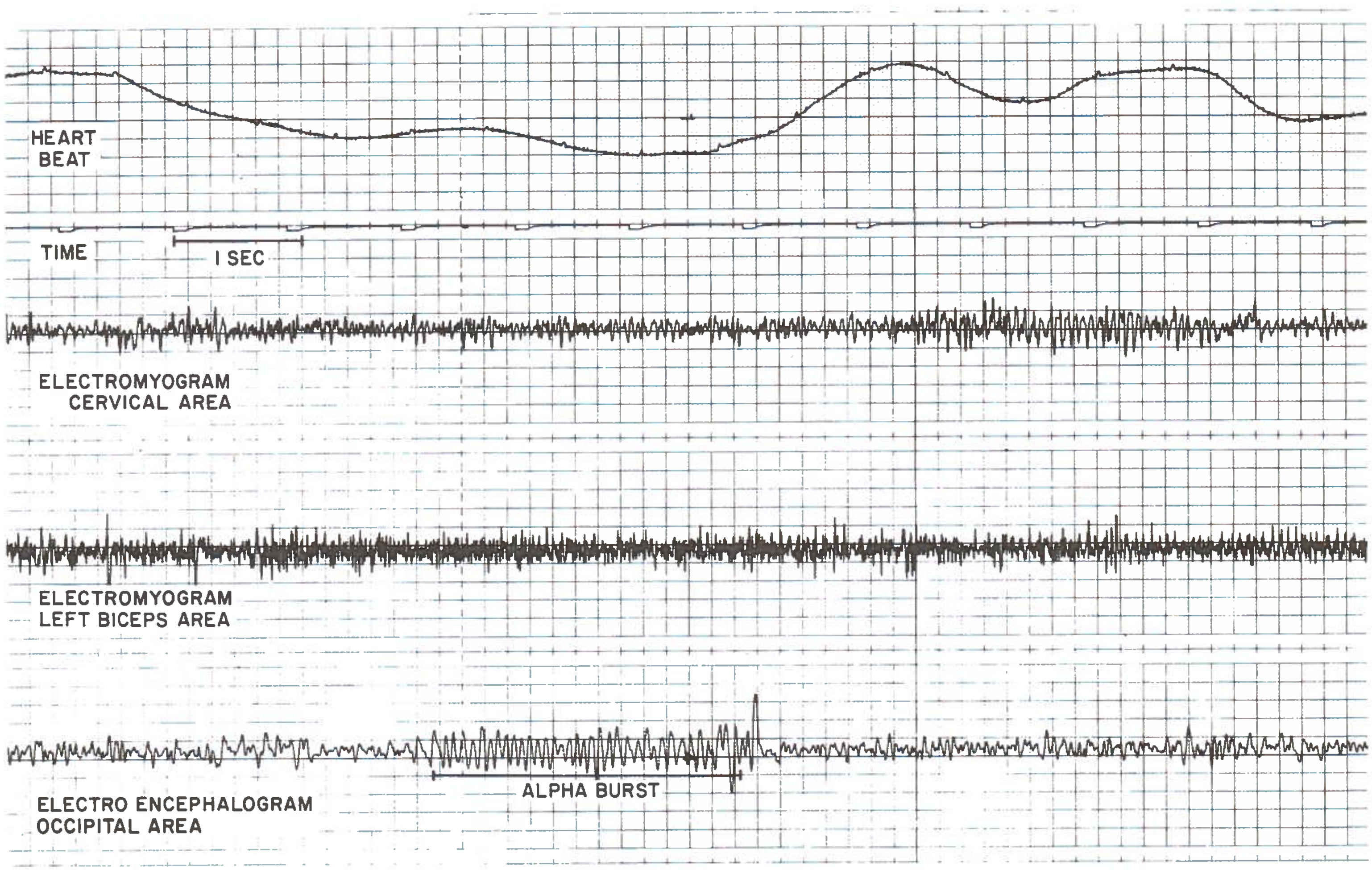

Figure 3-1. Physiological Recordings from Engineer

3.2.4 Engine and Train Measurements

The second category involves measurements of the operation of the engine and the train and includes:

a. Current drawn by the traction motors. This is an indicant of the load on the engine.

b. Train brake pipe pressure. This is an indicant of the use of and forces of application of the train brakes.

c. Independent brake pipe pressure. This is an indicant of the use of, and force of, application of the engine brakes.

d. Position of forward-reverse control.

e. D.C. speedometer voltage. This is an indicant of the rate and direction of travel of the train.

f. Outputs from x, y, z oriented accelerometers. These reflect the acceleration encountered due to changes in rate of travel; changes in the direction of travel (centripetal force and sideways); and the vertical force due to irregularities in the track.

3.2.5 Other Measurements

In addition to these ten variables, two other forms of data are recorded. An eleventh data channel is devoted to the verbal comments of an observer regarding train position, traffic, and other pertinent factors. The twelfth channel is devoted to the time signal broadcast by WWV. This channel is used for synchronization and documentation purposes.

3.2.6 Progress

Progress to date in this task includes the installation and calibration of the necessary sensors, signal conditioners, and recording and support instrumentation in a Baldwin Roadswitcher Engine on the Crane railroad and making test recordings with a Crane train crew during actual service.

The recordings made have been analyzed by TSC and they have revealed areas where future refinements are necessary. In particular the pressure transducers and accelerometers are judged insufficient due to inadequate low frequency response. Pressure transducers and accelerometers with low frequency limits approximating dc are on order. However, the recordings also demonstrated the utility of the selected electrophysiological sensor techniques in that useable recordings were made from an engineer in service without unduly encumbering him. Figure 3-2 is a photograph of an engineer with the sensors attached. The sensor wires visible in the picture are attached to silver disc electrodes which are fastened to the surface of his skin with surgical adhesive tape. The sensor wires are connected to the recorder through a nine-pin quick disconnect plug attached to his belt. In the event the engineer must leave his station, he merely disconnects the plug and reconnects it when he returns.

3.2.7 Future Efforts

Future efforts on this task will include the addition of a time-lapse photography system to provide a visual record of the engineer, cab, and exterior, and the development of practical real-time processing using an on-board digital computer. With regard to the use of the computer, the present technique requires continuous recording of all sensor imputs. Therefore an eight-hour recording might require the examination of eight hours of recorded data in order to determine which portions of the recording are of sufficient interest to warrant further analysis. To eliminate this requirement, an alternative, and somewhat novel, approach will be attempted after the initial continuous recording system has been reduced to practice. Called a "window recording" system the multichannel magnetic recorder is replaced by a small digital control computer. This "on-board" computer constantly monitors all incoming data and stores it for one minute in a temporary storage loop. When any of the incoming data changes value sufficiently to trigger the permanent storage program, both the entire preceding minute and the following minute are placed in

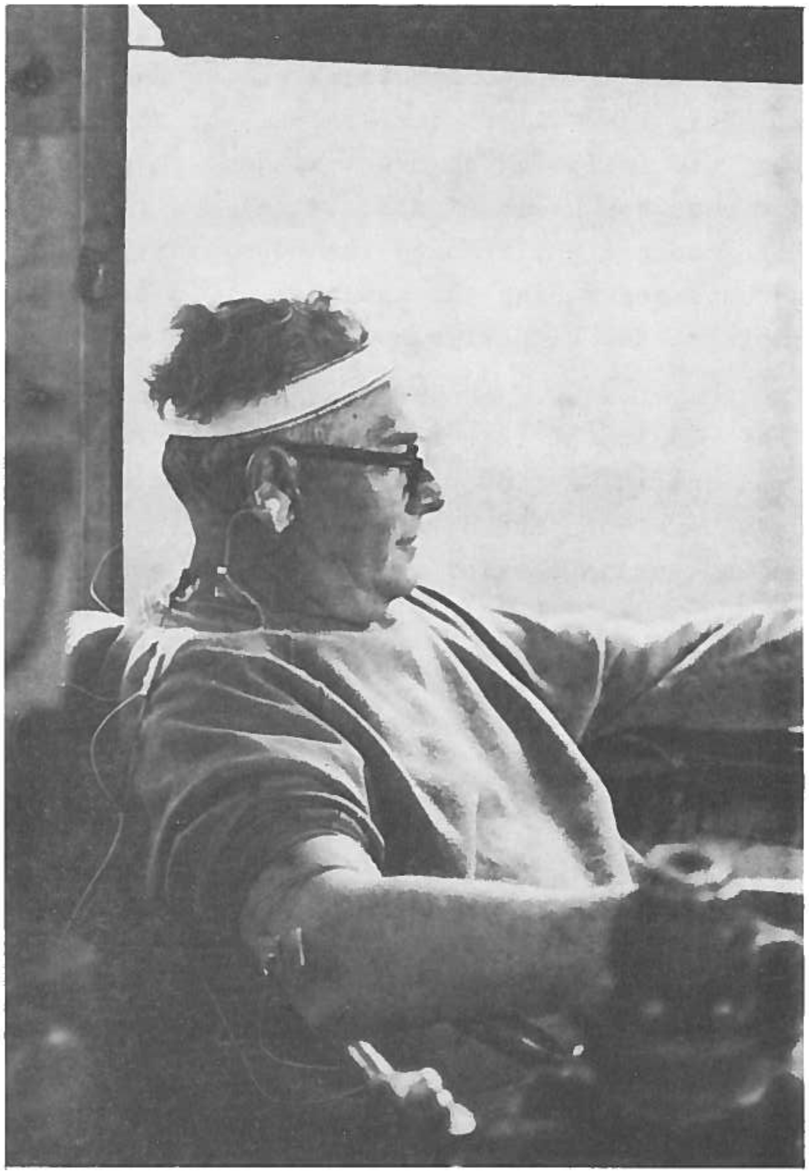

Figure 3-2. Engineer with Sensors In Place

permanent storage on digital tape. For example, if the computer were programmed to record the "window" around a service brake application whenever the engineer reduced the pipe pressure by more than 12 pounds, the computer would store the two minute periods surrounding the event. Obviously similar changes on any of the other data channels or combinations of channels could trigger the program. This then allows the analysis of occurrences leading up to, during, and following an event without recording hours of eventless and possibly useless data. It allows rapid access to the events of interest and reduces the possibility of loss of data through omission during the analysis. Use of the computer will also increase the effective number of channels by more than a factor of two.

While the results of this task will not be available in time to augment the initial set of regulations, it is anticipated that the techniques developed and data obtained will be of great value in understanding human behavior in the railway operational environment.

4.0 ACCIDENT ANALYSIS

4.1 INTRODUCTION

During FY'72, TSC has been engaged in a cooperative effort with FRA and its contractor, Tolis Cain Corporation, to review the FRA accident reporting system and to identify areas within this system where the analytic needs of those charged with railroad accident study and evaluation of accident avoidance measures are not satisfactorily met. Specifically, the activities of TSC in this effort have concentrated on developing a preliminary list of data items relating to the performance of human elements in railroad operations and on defining ways in which these data items might be utilized in the course of accident study. The initial goals of generating such a list and rationale by which to judge the individual importance of additional items prior to recommending inclusion in the accident data base have been met. Items thus far judged to be critical in accident analysis have been introduced into the data system being designed by the contractor.

The list of human factor data items as represented in the Tolis Cain document entitled, Report on Information System Requirements and System Recommendations: Vol. 2, 10 Jan. 1972, constitutes, in our judgment, an incomplete specification of those elements of operating crew qualification, training and on-the-job performance which will ultimately have to be addressed if the significance of the human factor in railroad accidents is to be assessed. The process of adding data items to this incomplete list is, however, difficult if any sort of return-on-investment criterion is used in judging the merit of each added element. Costs in time and dollars through the various phases of data acquisition and recording, storage, processing and reporting increase rapidly as the number of dimensions of which one desires information goes up. Thus, it is appropriate that means for identifying critical data items and for establishing priorities on their collection and use be generated very early in the design process. Efforts to generate such means have been a major preoccupation to date and they form the core of the TSC activity proposed for the coming year in railroad accident investigation.

The remainder of this section deals with the rationale underlying the proposed activity and its essential requirements and characteristics. In preparing this section, we have chosen to present our thoughts more or less chronologically, that is, as they have occurred through the year. Such a presentation will, we hope, aid the readers' understanding of the essential problems as we see them and facilitate a critical review of the solutions proposed.

4.2 DEVELOPMENT OF PRELIMINARY LIST OF DATA ELEMENTS

A standard justification for developing a new reporting system of almost any variety is that the needs of users are not satisfactorily met by the capabilities of the system currently in use. The generation of such a justification, particularly within the user community charged with study and analysis of the phenomena reported (as opposed to those charged with straight reporting) is materially aided if one can find in a current system, instances in which the acquisition of additional data or a substantive change in the way the available data are collected, processed or reported could engender better understanding of the variables of interest. If it is the case that these variables of interest represent significant sources of cost (in safety, efficiency, etc.) when they go uncontrolled and, with the aid of the reporting system, they can be understood at a level which allows for effective control, then, from some point of view, the case for adoption of the new system is clear. If, in addition, the cost of designing and operating the reporting system and of achieving and maintaining the desired control are less than the cost associated with failure to control, then, from almost any point of view, the case for adoption is totally clear.

With such an oversimplified model, we initiated a general study of selected railroad operations, particularly those having to do with control of the train by the engineer, and requirements for the operation of signals and other communication media. Our first efforts also included study of operating rules as set forth in the Standard Code and as supplemented in the rule books of several class 1 railroads. It was anticipated that as a result of such background study:

a. We would be in a position to analyze data provided in the Accident Bulletin.

b. That we could, through appropriate compilation and analysis of the human factors data contained therein, identify specific accident categories where complete understanding of the relationships between causal elements required the collection of additional data;

c. That we could develop estimates of the order in which additions and revisions should be made to the human factors portion of the data base;

d. Finally, that we could estimate the probable return on investment resulting from such additions and revisions of data on the basis of the relative frequencies and severities of the accident types identified above.

If our expectations concerning steps to the generation and justification of a list of human factors data items were appropriate, our judgments concerning the dispatch with which these steps could be accomplished was not. It became quite clear on examination of such formal report documents as the Accident Bulletin, the Monthly Summary of Accidents* and the Preliminary Report** that basic information which would be required in the assessment of the relative contributions of different types of human errors to different types of train and non-train accidents was not available. At the most, one could only hope to estimate the total number of accidents in which human error (categorized as "negligence"

*Full title: Summary of Accidents Reported By All Line-Haul and Switching and Terminal Railroad Companies. (issued each month)

**Full title: Preliminary Report of Railroad Accidents and Resulting Casualties. (issued each month) of a given type) was reported to be a (single) cause and then to compare that number with the total of accidents in which equipment failure was credited as a (single) casual agent.

In all cases, of course, the statistics published in the Accident Bulletin were concerned with proximal causal factors - that is, factors which stood in close temporal proximity to the accidents themselves. Particularly where these causal factors related to the apparent violation of rules; little insight could be generated concerning the distal factors which produced the conditions under which the rules were violated. Thus, even if it was possible on the basis of the published statistics to generate a meaningful set of data elements relating to the performance of the human element at the time of or shortly before the accident, it would not have been possible to identify elements farther back in the causal sequence in a less than arbitrary manner.* The conclusions that we came to at this point were that the accident data as currently acquired and published were of little use in the effort to understand the contribution of errors in human performance to the total accident picture and that little could be done to the system in the way of local "repair" which would materially increase its utility. Our conclusions appeared to be in accord with those coming out of the Tolis Cain survey of the requirements of a broad range of users of railroad accident data and of the dissatisfactions of these users with the current FRA system. A total redesign of the system around a multiple contributory cause factor philosophy seemed to be indicated.

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*NOTE: It is important to note here that a document of the sort represented by the Accident Bulletin is intended primarily to report out at a high level of aggregation the accumulated experience of the various operational entities (in this case, railroads) over a specified time period. As such, it may be inappropriate to expect that the document would provide data (particularly on human factors) in a form which allows any sort of detailed causal analysis. It would clearly be inappropriate if the data enabling such analysis were at least gathered and maintained at a lower level within the system. Our examination of the basic data acquisition forms (Form T and Form T Supplement) however, indicated little likelihood that human factors data of any sort are acquired except indirectly as part of the narrative description of a given accident.

(Continued on next page)

In the absence of direct guidance from the current system, it was decided that generation of a list of human factors elements would have to be accomplished indirectly from two different directions: (1) we would concentrate on identifying those (distal) variables of which the performance of personnel could be reasonably expected to be a function; the list could then be started with the specification of data items relevant to these variables. (2) we would attempt to generate a procedure by which the (proximal) job performance elements themselves could be identified. As they were identified, then, they would be added to the list begun in (1).

Variables which would normally be expected to impact performance on the job were considered to be:

(a) Criteria for personnel selection;

(b) Method, duration and quality of training;

(c) Criteria for and method of certification (or equivalent);

(d) Medical history;

(e) Duration of service;

(f) Exposure to prior circumstances which resulted in an accident or near accident;

(g) Activity immediately prior to the current accident.

Notable exceptions to the general observation that formal accident FRA reports do not contain the "raw material" on which to base judgments concerning the relative contributions of human factors are the Summary Reports issued in connection with specific accidents which result in loss of life and/or extensive property damage. These reports typically present considerable data concerning conditions antecedent to an accident, and in those cases where multiple factor causation is indicated, provide insight into the relationships among the factors. It is our feeling at this point that if reports containing an amount of detail similar to that of the Summary Reports could routinely be generated from the standard data base (rather than as the result of a full-scale post-accident investigation), the latter might be considered to be adequate for at least gross study of the significance of the human element in accident causation.

It was assumed that much of the relevant data within this set of distal elements was already maintained (or at least collected) by the railroads as part of their normal operations and that arrangements could be made to collect and maintain the remaining data if it proved over time to be of high utility in the study of accidents. The important point, as far as we were concerned, was that the elements were included in the total data base available to investigators. Except for a few items which would have to be collected at the scene of the accident, the choice of which items to collect thusly and which to acquire later, either directly or indirectly through the accident reporting system, was left to the designers.

With these considerations, the following preliminary list was generated for Tolis Cain:

1.0 Identification of crew

2.0 Hours of duty up to time of accident

3.0 Hours prior rest

4.0 Identification of last duty
- 4.1 Where
- 4.2 When
- 4.3 How long on duty

5.0 Time in employ of this railroad

6.0 Identification of prior service (other railroad employment)
- 6.1 Where
- 6.2 When
- 6.3 Type of duty

7.0 Characterization of training provided for employee on this road

8.0 Prior accidents in which crew member(s) was (were) involved
- 8.1 Location
- 8.2 Date
- 8.3 Apparent cause
- 8.4 Remedial action taken (retraining, etc.)-if applicable

9.0 Results of last physical exam (fitness profile)

As a result of TSC activities in areas concerned with selection/training and medical standards for railroad personnel (reported on elsewhere in this document), relevant items on this list were later broadened as follows:

Item 7.0: Characterization of training

7.1 Training curriculum (I.D. Code)

7.1.1 Date completed
7.1.2 Type of exam completed (oral, written, etc.)
7.1.3 Score on examination
7.1.4 Identification of examiner
7.1.5 No. of attempts to complete exam

7.2 Railroad Speciality Course(s) Taken

7.2.1 Type of course (I.D. Code)
7.2.2 Date completed
7.2.3 Type of exam (written, oral, etc.)
7.2.4 Score on examination
7.2.5 Identification of examiner

7.3 Annual Refresher Course(s) Taken

7.3.1 Type of course (I.D. Code)
7.3.2 Date completed
7.3.3 Type of exam (written, oral, etc.)
7.3.4 Score on examination
7.3.5 Identification of examiner

7.4 Qualification Examinations

7.4.1 Occupation Category
7.4.2 Date completed
7.4.3 Type of exam
7.4.4 Score on examination
7.4.5 Promoted/Requalified
7.4.6 Identification of examiner

7.5 Safety Courses Taken

7.5.1 Type of course
7.5.2 Date completed
7.5.3 Type of exam
7.5.4 Score on examination
7.5.5 Identification of examiner

Item 9.0: Physical Fitness Profile

9.1 Hearing Defects

9.1.1 Type of defect
9.1.2 Type of examination (Audiometer, etc.)
9.1.3 Extent of defect
9.1.4 Date of examination

9.2 Vision Defects

9.2.1 Type of defect
9.2.2 Type of examination (Orthorater, etc.)
9.2.3 Extent of defect
9.2.4 Date of examination

9.3 Cardiovascular Defects

9.3.1 }
9.3.2 } as above
9.3.3 }
9.3.4 }

9.4 Other Abnormal Conditions

9.4.1 Diabetes
9.4.2 Ulcers
9.4.3 Colitis
9.4.4 Fainting/Dizzy Spells
9.4.5 Alcohol and/or Drug Dependencies

In addition, the following items, which would normally be of concern at the scene of the accident, were specified:

10.0 Evidence of use of drugs (or alcohol); if evidence present, indicate type of drug (or blood alcohol level)

11.0 Locations of members of train crew(s) at time of accident; estimate of period of time at those respective locations prior to accident.

12.0 Description of last communications, if any, between head end and caboose (including train whistles, hand signals, etc.)

13.0 Description of last communications if any between members of head end crew.

14.0 Description of actions taken by crewmen addressed in above communications.

With the generation of a list of distal elements thus begun, we turned our attention to formulating a method by which to identify further distal elements, and, more importantly proximal elements which would require attention at the accident scene. The next section details a proposal which is a result of this effort.

4.3 PROPOSAL FOR IDENTIFICATION AND EVALUATION OF ADDITIONAL HUMAN FACTORS ELEMENTS

In order to conduct analyses of railroad accidents which may admit of multiple contributing causes, a large body of relevant data must be accessible to the investigator. The need for some of these data can be judged in advance and steps can be taken (e.g.) through suitable training of on-site investigators, careful design of data recording forms, etc. to ensure appropriate recording of observations. The need for many other (sometimes crucial) data cannot be forecast with current methods. Hence, they go unrecorded and unanalyzed. In such circumstances, while the major cause of the accidents may well be clear, investigators can be hard pressed to make recommendations which will unequivocally reduce the probabilities of similar accidents in the future.

A major requirement, then, is to develop a procedure which will ensure that the data recording process is formally exhaustive at a level of detail which is sufficient to provide insight into multiple cause/factor accidents without, at the same time, multiplying the cost and time associated with conducting investigations.

The position is taken here that a procedure which has a high probability of meeting this requirement is the failure mode technique. Such an analytic technique would have, as its object, a delineation of all of the ways in which an accident of a given type (say, a rear-end collision at a main line and spur track) could occur due to failures in equipment and/or procedures. For each of these causes (ways) further delineations could be made of antecedent conditions, yielding a "fault-tree" structure which contained all the logical conjunctions and disjunctions (and's and or's) of causes and effects related to that accident type. On completion, such a structure would yield a map of all the cause and effect routes which could be taken in the course of generation of that type of accident. More significantly, it would yield an indication (before the fact) of the data which would need to be collected if one were to discriminate one set of possible routes from another set in the course of a study of a real accident of this type. For example, in the tree shown in Figure 4-1, it is clear that only information concerning the joint occurrence of factor a and factor e will aid the discrimination between causes B and C of accident A. The mere observation of a and e is not sufficient to establish the cause though each can be a contributing factor. Presumably then, the investigator can make certain that data regarding this dependency will be a part of his data base.

An additional benefit to such an analysis is that it provides a mechanism for determining what redesign of equipment and/or procedures will effect the maximum reduction in accident potential. Referring again to the diagram, it is clear that to reduce the occurrence of "B-type" causes, one could set out to eliminate the possibility of a, e, f or c.

Elimination of either f or c might be appropriate if, in fact either was a factor in a significant number of accidents. A more reasonable approach, however, might be to redesign equipment or procedures such that a and e could not occur simultaneously. A third alternative which might be pursued would be to eliminate e, since in our example, it is implicated as a factor in three different

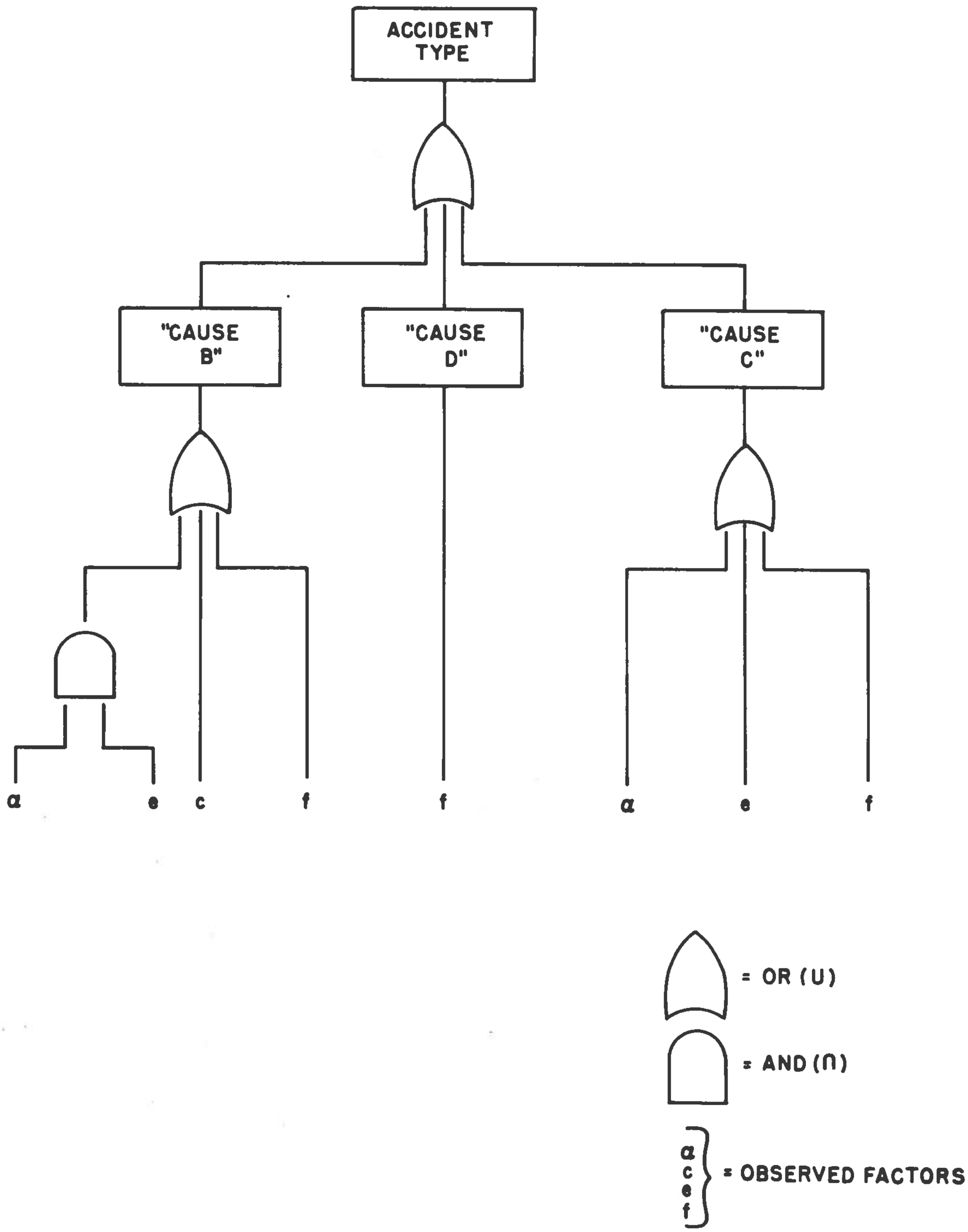

Figure 4-1. Fault-Tree Structure

accident causes. Such an analysis clearly does not establish what should be done, but once frequency data are accumulated, it does indicate what can be done. If the costs of pursuing each of the alternatives is established, the analysis aids in choosing the most cost/effective solution.

Some notes are in order concerning the limitations of such an analysis and on its essestial conditions:

a. An analysis of this sort does not provide a framework which will enable one to predict directly the expected frequency of future accidents or to speculate on their probable causes. It is predictive only in the sense that it indicates that if such events occur in close proximity, they will result in a (specified) outcome.

b. It has zero utility if the data acquisition and recording system which it helps to specify is not implemented. For each mode (cause/effect element) identified in the (tree) diagram for a given type of accident, it is necessary that a corresponding data element be addressed during the accident study.

c. The analysis should be performed in the context of both equipment and procedure (human) failure modes. Since these modes are likely to have significant interconnections at man/machine interfaces, limited utility would be expected in the event that only one variety was explored.

d. The benefits to be derived are (probably) related closely to the degree of detail in the diagrams. This is particularly the case where failure to perform required procedures or their performance out of sequence is critical to safe operation.

The actual use of such a technique requires, of course, continued posting of accident data and observation of results as modifications are made in the systems and procedures. In addition, as significant modifications are made and potential causal factors begin to drop out, the logical structure must be regenerated.

TSC proposes to develop a series of "fault-trees" for four particular accident types to serve initially as a basis for establishing the set of human performance data elements which should appear in an accident investigation system, to demonstrate the utility of the failure mode technique in accident study, and, later (following validation) to serve as actual operational tools for investigation of the accident types described. Types proposed for study here are selected either because they occur with high frequency or because they are costly or both. They are as follows:

a. Train accident: collision

b. Train accident: derailment

c. Train-service accident: coupling/uncoupling locomotives/cars

d. Train-service accident: getting on/off locomotives/cars

In the course of the effort, it will be necessary to define a set of boundary conditions and (particularly) the "train accident" types. For example, it will be required that a "collision" type be defined somewhat as follows: "Rear-end collision (collision of front of moving train with rear of standing train) outside of yard limits in territory controlled by train orders." Considerable effort will be made, however, to maintain as much generality as possible so that the analysis will be descriptive of a family of accident types rather than of a specific accident.

4.4 SUMMARY

We have reviewed the official FRA publications on accidents and attempted to judge their utility as a data base from which to establish the actual contribution of the human element to railroad accidents. With the possible exception of the Summary Reports, we have found that these publications, though they may well serve a legislative reporting function, do not provide sufficient data to ascertain the "why's" and "wherefors" of human errors in judgment and of apparent rule violations. Moreover, we have not found the data that are provided to be in a form which materially aids the process of specifying and justifying data elements to be appended on a piecemeal basis. Our conclusion that the system is in need of total redesign...though reached as a result of more provincial considerations (viz., the quality of the human factors data base alone)...mirrors that of the FRA's contractor, Tolis Cain, and of many FRA personnel.

To begin the process of specifying human factors data elements to be accomodated in the new accident reporting system being designed by Tolis Cain, a preliminary list of items relevant to the selection, training and medical qualifications of railroad operating personnel was generated. These items, by and large, enable systematic study to be made of the effects on accident frequency of changes in normative criteria. They form, in our judgment, a necessary background for the revision of training programs, medical standards, etc.

In addition to this effort, we identified and proposed a programmatic technique for isolating critical aspects of human performance in train operation. This proposal relies mainly on the application of failure mode analysis to sequences of manual operation and seeks to develop a set of failure "templates" which can be used to identify data items whose acquisition at the scene of the accident is critical. We anticipate the eventual payoff in this activity to be in the areas of operating rule and procedure revision.

We are convinced, as a result of our study in FY72, that the contribution of the human element to railroad accidents is extremely significant. We are also convinced that the data currently available are insufficient to establish more than that basic conviction. And, we feel that it can only be as a result of very careful analysis of error modes that the contribution of that human element can ever be significantly reduced.

5.0 SIMULATION REQUIREMENTS

5.1 INTRODUCTION

Although railroads have been a major means of transportation for well over 100 years, the first railroad locomotive and train simulator went into operation less than ten years ago. Furthermore, of the four simulators now known to exist, two, the first two built, are in other countries, namely, England and Japan. The simulator in England was designed for the transitional training required for the shift over of British Railways from steam engine and diesel to high-speed electric locomotives. The simulator in Japan is purported to be for research in human factors in railway operations. The two simulators now operating in this country were designed and built for training railroad engineers. From information gathered on visits to these two simulators, there is every indication that as training devices, railroad locomotive and train simulators, have proven to be cost-effective. The Southern Pacific Transportation Company, which owns one simulator has asked for bids for the procurement of a second unit; a sure indication that railroad locomotive and train simulators, at least as training devices, have come of age in this country. On the other hand, the much younger aerospace industry has had a relatively long history of effective use of simulators, not only for training but also for research and development. The Japanese railroad industry has apparently also used simulators effectively for the research and development in human factors needed for their Tokaido Line. In this country, however, the practicality of the use of the railroad locomotive and train simulator for research and development has still to be determined. If the Federal Railroad Administration only verified the practicality and the validity of the use of simulator for research and development, this alone could well justify the procurement, since such results could help spark the same type of rapid technological advancement which has occured in the aerospace industry.

Task 5-A, PPA RR209, "Human Factors in Railroad Operations," raised the questions of the justification for the procurement by the Federal Railroad Administration of a railroad locomotive and train simulator for purposes of research and development, and, if justified, the specification for such a simulator, In answer to this first question, the significant impact of the behavior of the railroad engineman on the research and development required in railroad operations, as reviewed below shows quite conclusively that benefits in both safety and time, and therefore costs, are to be derived from the use of a railroad locomotive and train simulator for research and development purposes. No attempt has been made, however, to generate any dollar-values for these benefits in safety and time. Specifications for a simulator capable of fulfilling the needs of the required program of research have been submitted to the FRA, and procurement is under consideration.

5.2 HUMAN FACTORS RESEARCH AND DEVELOPMENT FOR TRAIN HANDLING

5.2.1 Need for Simulation in Safety Research

An extensive program of research and development is required, if the Federal Railraod Administration is to achieve the goal of increased safety and effectiveness of railroad operations pursuant to the "Federal Railroad Safety Act of 1970." The safety and effectiveness of railroad operations depends, to a large extent, on the safety and effectiveness of train handling, the province of the railroad engineer. Obviously, any program of research and development to reduce the frequency and severity of train accidents and to increase the effectiveness of railroad operations shall depend directly on the engineers operating the trains. Thus, common to all aspects of the program is the requirement for a means of measuring the performance of the railroad engineer while handling a train. As the aerospace industry has found, most such measurements cannot be made safely, economically and within a reasonable time frame, if actual equipment under actual operating conditions has to be used. In addition to safety and economics, the use of a locomotive and train simulator would allow for complete control of the operating conditions, which is a necessity if valid data are to be attained throughout the course of the research and development program.

5.2.2 Lack of Statistical Data

The development of a program of research and development on a quantitative basis is hampered, however, by the state of the statistics on railroad accidents. The inadequacies in these data require that decisions on the allocations of priorities and level of effort for the various research and development areas in train handling must be made, however reluctantly, on a qualitative basis. This lack of adequate accident statistics is the reason that no attempt has been made for generating dollar-values for the benefits to be derived from this research and development program and the use of a railroad and locomotive simulator; the cost benefits must be judged on the basis of the face validity of the research and development requirements per se.

5.2.3 Research Areas Benefitting from Simulation

Human factors research and development for train handling can be classified as in five main categories. These categories do not benefit equally, however, from the use of a railroad locomotive and train simulator, nor are they generally equal in cost-effectiveness. In order of judged increasingly beneficial research and development, these five areas are:

a. Engine cab control and display layouts;

b. Physical and physiological factors;

c. Accident reconstruction and analysis;

d. Test and evaluation of train handling concepts;

e. Research and development in skill acquisition.

Each of these areas will be considered and the rational for the value judgment will be given.

5.2.3.1 Engine Cab, Controls, and Display Layouts - From the point of view of human factors, very little, if any, consideration was given to the capabilities and limitations of the engineman when the engine cab, controls and displays were designed and laid out. This lack of consideration of human factors in the past does not mean, however, that a program of research and development is required to correct this problem. There are surely sufficient data in the various human engineering handbooks and reports for the solution of the problem of engine-cab design and layout. Furthermore, the probabilities are very low that any new locomotive cab design and arrangement can be shown to be statistically more effective than the present one. To show a practically significant difference is judged to be beyond the realm of possibilities. The problem of locomotive cab, control, and display layout can best be met by the cooperation of the design engineer and the behavioral scientist working as a team to ensure that the known human factors data are used. A complex dynamic locomotive and train simulator is certainly not a requirement for this problem area.

5.2.3.2 Physical and Physiological Factors - In view of the Federal medical requirements for the other modes of transportation, there should be no doubts as to the importance of these factors in railroad operations. Furthermore, there is no reason to believe that for railroad transportation the regulation on these factors should be any more or less restrictive than for the other modes. Research on these factors including such problems as the use of alcohol, narcotics, prescription and non-prescription pharmaceuticals in railroad operations should be supported, but to do this work on the simulator is questionable. Because of the high face validity of any data obtained with a simulator such as the railroad and train simulator specified herein, negative-results, e.g., on the effects of low doses of alcohol, could create serious problems. In the area of physical and physiological factors, the railroad locomotive and train simulator should be used only after full consideration of all the potential problems.

5.2.3.3 Accident Reconstruction and Analysis - The reconstruction and analysis of accidents can be described as a high risk, high profit venture. There is on record, however, at lease one case in the aviation industry in which the use of a flight simulator enabled investigators to solve a problem which had already caused a number of fatal accidents costing millions of dollars. In this case, a behavioral scientist questioned the cause for the sudden increase in accidents during night approaches under conditions of good visibility. His hypothesis of the cause for these accidents was tested and validated successfully on a flight simulator. Such cases do not occur very often, but when they do, the cost-benefits pay for the simulator many times over. The specifications for the railroad locomotive and train simulator were drawn up with the view that the simulator would be able to be used in accident reconstruction and analysis.

5.2.3.4 Test and Evaluation of Train Handling Concepts - For whatever the reasons, relatively little modern technology has yet been applied effectively to the problems of train handling. Only with the application of modern technology, however, can the railroad industry hope to retain even its present share of the transportation market. Improvements must be made in train handling to increase the effectiveness of train handling and, therefore, the safety of railroad operations.

Any program of development of a complex man-machine system runs the risk of failure. The risk is drastically reduced, however, if, whenever possible, the man-machine interface of the system is simulated, tested, and evaluated. The records are full of cases where the costs of this procedure have been considered excessive or unnecessary and the system implemented only to be found a dismal failure. In such cases, either the system never becomes functional or extremely expensive redesigning and retrofitting are done. Untold waste occurs in either event. In view of the high costs of modern technology all reasonable steps must be taken to reduce the probabilities of failure.

The railroad and train simulator was designed with research and development in train handling as one of the two paramount areas of effort in which it would be used. This simulator will allow any number of train handling concepts for any number of train types, both standard and experimental, to be tested and evaluated not only quickly and economically, but, even more important, safely. The performance envelope of a new concept for a power consist can be determined with no danger to either property or personnel.

The efforts in the area of train handling will also interact with the efforts in skill acquisition and retention which follow. Hopefully, as the information transfer requirements are identified and quantified as is necessary for effective skill acquisition and retention, these results will contribute to the development of new train control concepts and systems which will increase the safety of railroad operations.

5.2.3.5 Research and Development in Skill Acquisition and Retention - Of all the common carriers, the railroad industry is the only one in which the operator, the railroad engineer, is not licensed or certified by any Government organization at either the state or Federal level. For that matter, no formal standards or qualification of proficiency exist for all the potential dangers to the general public from poorly or inadequately trained railroad engineers. Because of the poor financial condition of so many of the railroads of the nation, the need for standards and qualifications of proficiency for the engineer is greater than ever; some roads drastically curtailed skill acquisition and retention programs as economy measures. Surely, this state-of-affairs is not due to the skill level required by the railroad engineer, or that the railroad engineer has no responsibility for the safety of the public. Proficiency standards and qualifications for the railroad engineer are certainly required, if the safety of the public and of the engineer himself are to be protected.

The cost benefits to be derived from the use of a railroad locomotive and train simulator in an effort to establish standards and qualifications of proficiency for the railroad engineer should be more than enough to amortize the costs of such a simulator. The amount of research and development required to devise, validate, and establish these standards and qualifications shall be very extensive. The probable extent of the effort required was revealed by a cursory review of the tasks performed by the railroad engineer, whose skill requirements are much higher than might be first expected. He certainly appears to respond to many extremely subtle cues, cues which he himself might not be aware of. The full extent of the research and development requirements must await the completion of the formal review of the work performed by the railroad engineer.

5.3 SUMMARY

The Federal Railroad Administration requires a railroad locomotive and train simulator to conduct an effective program of research and development in the various areas of human factors in the safety of train handling. The areas of the program in which the simulator would be most effective were pointed out. The specifications for such a research simulator have been drawn up and submitted to the FRA.

6.0 SUMMARY, RESULTS AND CONCLUSIONS

6.1 SUMMARY

TSC provided consultation and research on human factors in support of FRA efforts to promote railroad safety. The principal areas of effort included:

a. Job analysis of the engineer;

b. Physical standards for railroad employees;

c. Accident analysis;

d. Simulation requirements.

In addition, support of the program was provided through the FRA in the form of a survey of vandalism, a survey of locomotive cab designs, and assistance in collecting in-cab physiological data.

Special activities included the presentation of special briefings to government, labor and management groups, attendance at selected professional meetings and human factors support to the Locomotive Control Compartment Committee.

6.2 RESULTS AND CONCLUSIONS

6.2.1 Job Analysis of Engineers

This effort is incomplete. Tentative conclusions are that the engineer plays a critical role in railroad safety since he controls the motion of trains, whose mass and velocity combine into a potential for creating great damage if control is lost. This potential can be disastrous if coupled with flammable, explosive or toxic loads in an area of high population density. Accident analyses identify a syndrome of causes related to lack or loss of attention that requires finer definition through controlled research. Although, in routine operations, a well-maintained locomotive cab is a relatively safe place to work, it is a lethal environment in collisions, even at low speeds. Since routine coupling operations are controlled collisions, considerable effort is being, and will be, exerted toward improvements in cab layout.

Physical attributes necessary for safe train handling have been identified (6.2.2). Much less is known about the requisite psychological attributes. Standards are being considered for the control of alcohol and drug usage, but the desirability and nature of psychiatric screening deserves further study.

Aptitudes tentatively identified as critical for safe train handling are, in descending order of criticality:

a. Decision making

b. Perception and memory

c. Symbolic data operations

d. Language ability

e. Motor skills

Further research on the development of these estimates into standardized tests for selection of personnel and for job proficiency evaluation is desirable. Consideration should also be given to personality evaluation and to the development of motivation and morale programs as incentives to safer operational behavior.

Training methods are generally archaic in the railroad industry, although there are hopeful signs of progress. A program is recommended to include:

a. A survey of current training;

b. Development of training standards;

c. Development of standardized proficiency tests.

6.2.2 Physical Standards for Railroad Employees

This effort is incomplete. Railroad jobs have been classified at standard levels of physical fitness and the medical examinations required to determine these levels have been tentatively drafted.

They are presently being evaluated by medical specialists. Following evaluation, specific recommendations for physical fitness evaluation will be submitted to the FRA.

To permit future refinement of physical standards for engineers, an experimental program for evaluating physiological stresses in the job is underway. Equipment has been assembled, installed and operated to demonstrate that useful physiological measurements can be recorded from the engineer in the cab without affecting his ability to work safely. Field studies are planned to collect measurements of physiological stress in routine operations in FY'73.

6.2.3 Accident Analysis

The human factors data currently available in published railroad accident statistics were evaluated for their utility as a data base from which to establish the actual contribution of the human element to railroad accidents. It was concluded that, to serve this purpose, much more information is needed on each accident. Necessary information relevant to the selection, training and medical qualifications of involved personnel was identified and recommended to Tolis Cain, the FRA's contractor for design of an improved accident reporting system. A programmatic technique for applying failure mode analysis to the identification of critical aspects of human performance in train operation was proposed and will be evaluated in FY'73.

6.2.4 Simulation Requirements

The use of locomotive and train simulators in training and research was surveyed. It was recommended that the FRA establish a research facility for the study of train handling based on a locomotive and train simulator. Specifications for the design of the simulator were drawn up and submitted to the FRA. Areas expected to benefit from such a facility include the following, in decreasing order of expected benefits:

a. Research and development in skill acquisition

b. Test and evaluation of train handling concepts

c. Accident reconstruction and analysis

d. Physical and physiological factors

e. Engine cab control and display layouts

6.3 THE PROGRAM FOR FISCAL YEAR 1973

As indicated in Table 1-1, this program is a continuing effort. The findings of one year's work are reflected, then, in the tasks given priority for the next year. The principal tasks for Fiscal Year 1973 are the following:

a. Continue development of standard job descriptions of all railroad operating personnel.

b. Support FRA efforts in standardizing procedures for investigating human factors in railroad accidents.

c. Support FRA efforts in issuing and evaluating physical standards for railroad employees.

d. Support FRA efforts in developing standards for railroad operating rules and railroad signals.

e. Survey the state-of-the-art in training for railroad operations and recommend training standards.

f. Establish a simulation facility and its research program.

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APPENDIX

TASK ANALYSIS OF SELECTED RAILROAD OPERATING POSITIONS FOR THE PURPOSE OF APPLYING STANDARD EMPLOYEE MEDICAL QUALIFICATIONS

BY

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GENERAL DISCUSSION

Safe and efficient operation of a railroad requires the coordinated efforts of employees performing many different tasks. However, man failure in certain positions is more immediately critical to the safety of persons and property than failure in other positions. Hence, the first efforts of the Federal Railroad Administration to prescribe national standards for employee qualifications should be directed to those employees directly involved with the movement of trains, locomotives, and railroad cars.

TYPES OF OPERATION

The types of operation commonly performed may be broadly classified as:

1. Yard Switching

   This process involves an engine and crew classifying cars on yard tracks according to destination and reassembling them in proper order on departure tracks for forwarding in "road" trains and, in the process, placing defective cars on designated tracks to be held for repairs.

   The yard switcher engine may also place and pick up cars at industrial sidings and do other work as required.

2. Local Freight or Road Switcher

This crew's assignment consists of taking a train of cars from an initial terminal and then placing or picking up cars at industrial tracks and public delivery tracks within an assigned territory. This assignment may also include yard switching.

3. Thru Freight Train

This train normally runs from an initial terminal to a final terminal without stopping except to change crews and/or power; however, it may be required to drop or pick up blocks of cars at intermediate points.

4. Passenger Train

This may be a high speed train stopping only at major points or it may be a train providing local or commuter service.

Train operating personnel may work interchangeably in any of the foregoing types of service when qualified.

TRAIN CONSIST

A train may be a single self-powered unit or it may consist of more than 100 freight cars and be powered by one or more engines.

An engine may consist of a single locomotive unit or of a number of locomotive units coupled together. When such multiple units are properly equipped, they are operated by a single engineer located in the leading unit. In certain instances, the engine at the head end of the train may be assisted by a manned "pusher" engine at the rear end or by a "slave" locomotive controlled by the engineer at the head end of the train by means of radio.

A "caboose" or "cabin car" is provided, at the rear end of all road freight trains, for certain train crew members, for emergency tools, and in most cases, for living quarters. The caboose is designed to permit crew members to inspect their train enroute and is provided with an air gauge and an "emergency" or "Conductor's" valve by means of which the train may be slowed or stopped from the rear end. A yard switching crew will not normally have a caboose while actually performing classification and switching work.

It is noted that a road freight train consisting, for example, of an eigine, 100 cars, and a caboose, is over a mile in length. It is further noted that the "slack action", (i.e., the free movement of cars within the train), may amount to over 50 feet; this means that the head end of the train may accelerate over 50 feet or more before the last car starts moving and vice versa. These are important considerations for the train engineer.

Passenger trains may consist of self-powered units used singly or in multiple and be operated by a single engineer or may consist of one or more conventional locomotives and conventional passenger cars. Passenger train cars are provided with tight couplers to eliminate slack action and with train air signal equipment so that the train crew may communicate with the engine crew.

MANNING

While the job titles enumerated in this task analysis are in common usage among railroads, the listing cannot be presumed to include all job titles that may now, or later, be used by individual companies. Hence, standard qualifications developed for employees within any category should apply to any employee whose normal duties fall within the general requirements and task descriptions applying to that category, regardless of title.

While the following discussion outlines the common practices followed in manning trains and yard crews, it must be noted that there may be variations in the number of men assigned depending upon:

1. Requirements for safely carrying out particular assignments;
2. Agreements with labor organizations;

3. The dictates of Federal or State laws, or of court decisions. It should be noted here that Federal law presently limits the hours of continuous service of employees engaged in or connected with the movement of any train to fourteen and requires at least eight consecutive hours off duty in the preceding twenty-four before such an employee goes on duty.

A road freight train is manned by a locomotive and a head-end or front brakeman stationed in the leading locomotive unit; a fireman may or may not be assigned. The conductor and one trainman, (brakeman or flagman), is stationed in the caboose at the rear of the train.

A self-propelled single unit passenger train is manned by an engineer, a conductor and usually one or more trainmen.

A multiple car passenger train is manned by an engineer and a firemean in the leading control unit. A conductor and as many trainmen as are required to work in the passenger and baggage cars. "Trainmen" may include brakeman, flagman, ticket collector, or baggageman as required.

A crew assigned to a yard switching engine normally consists of an engineer, a conductor and two helpers; a fireman may or may not be assigned. The engineer, and fireman if used, is stationed in the engine while the conductor and helpers work on the ground and/or ride equipment during switching operations. The conductor of a yard crew may be called a yard conductor, engine foreman, or foot board yard master; the helpers may be brakemen, flagmen, or yard helpers.

In all cases, the conductor is in charge and directs the operations of a train or yard engine and crew. The engineer is responsible for operating a train or yard engine safely in accord with instructions or signals given him by other crew members or from other sources.

CONTROL OF OPERATIONS

The control of a train or yard operation is governed by one or more of the following:

1. General instructions contained in the company's book of operating rules and other manual and permanent instructions such as rules for the use of air brakes, dynamic brakes, etc.

2. Special instructions contained in timetables and other papers and documents.

3. Specific instructions issued as bulletin orders or as train orders.

4. Wayside signals - fixed or temporary. Semaphore and/or colored light signals or position lights indicate if the track ahead is clear, and

   a. the permissible speed

   b. "stop"

   c. a route

5. Hand, lantern, flag and whistle signals.

6. Communications including telephone, teletype, and radio plus public address systems in yards. Radio systems in use include: train-to-wayside station providing communication between train and wayside control station, end-to-end providing communication between the caboose and the engine, and yard radio. Train men and yard men are commonly provided with walkie-talkie sets.

7. Supervision by train dispatchers, yard masters and other personnel.

8. Common sense and experience.

GENERAL REQUIREMENTS

For the purposes of this study, those positions directly involved with the movement of trains, locomotives, and cars have been grouped based on similarity of job functions and on the following occupational criteria:

1. Safety hazard potential in case of man failure;
   a. Critical
   b. High
   c. Medium
2. Physical demands in terms of strength and endurance;
   a. High
   b. Medium
   c. Low
   d. Minimal
3. Exposure to extremes of weather, (temperature, rain, snow, wind, etc.)
   a. High
   b. Medium
   c. Low
   d. Minimal

However, there are certain requirements which must be met by the employees in all categories, which are:

1. To know, and to be examined on, the company's book of operating rules as it relates to the employee's duties, which, among other things, include:
   a. The meaning of wayside signal aspects.
   b. The meaning of hand, flag, lamp, and whistle signals.
   c. Rules governing the movement of trains and the operation of track switches.

2. To know the book of safety rules

3. To know the schedules and instructions contained in the company's current working timetables as related to the employee's duties and to have a copy of such timetable with him while on duty.

4. To check orders, bulletins and notices related to the employee's duties before going on duty.

CATEGORY I

Positions Included

Locomotive Engineer, Fireman, Hostler

Safety hazard potential	Critical
Physical demands	Medium
Exposure to weather	Low

The locomotive engineer's job is the most demanding of those directly connected with train operation in terms of operating skills, alertness, ability to react properly to external signals from many sources, and training. Failure of the engineer to perform his functions properly can provide the greatest potential for:

1. injuries and fatalities to railroad personnel and to the public

2. damage to rolling equipment and to lading

3. damage to railroad and public property

The fireman's job is generally regarded as providing on-the-job training in order to qualify as an engineer. Hence, the fireman's duties normally consist of assisting the engineer, and of learning the physical characteristics of the lines or railroad over which he is to be qualified to operate, and the proper methods of safely handling trains under various conditions.

Train Directors, Tower Operators and Operators are responsible to the train dispatcher for all train movements within specific segments of the train dispatcher's territory. Operators may also control switches and signals located within yard limits in which case they are responsible to a yard master or to both a yard master and a train dispatcher.

A leverman, under the direction of an operator, operates mechanical or electrical controls to change the position of remotely located track switches and the aspect of associated signals. The position also provides on-the-job training.

Requirements

Train dispatchers and operators, in addition to the general requirements, must know the signal systems, if any, governing train movements within their territories, the arrangement of main tracks, and the types of switch lock controls.

Federal law presently limits the hours of continuous service of this class of employee to:

a. no more than nine hours in a 24 hour period where two shifts are employed.

b. no more than twelve hours in a 24 hour period where one shift is employed.

Tasks

Chief train dispatchers are responsible for the preparation of timetables and generally for the safe scheduling of all trains within their territories, with the assistance of train dispatchers, operators and other operating, mechanical and engineering department personnel.

Train dispatchers directly, or through operators:

1. Schedule and control following, opposing, or conflicting movements of trains by:

a. issuing train orders and instructions in writing and communicated directly or by telephone, telegraph, or radio.

b. controlling track switches and wayside signals either directly or by remote control; frequently, with the aid of a model board which shows by diagrams and lights the track occupancy and position of track switches and associated signals.

c. granting permission for trains to occupy tracks where train movements are governed by automatic signals activated by the trains occupying the track.

2. Maintain permanent records of train orders and permissions issued and the pertinent data concerning all train movements.

3. Issue permissions for track cars and working trains to occupy specific tracks for specific periods of time.

4. Visually inspect passing trains if in a position to do so.

5. Watch the graph recordings of hot box detectors, if provided, and activate a remotely controlled stop signal if a hot box is detected, then advise the train crew of its location in the train.

CATEGORY IV

<u>Positions Included</u>

Group 1 Gate Tender, Gateman, Crossing Watchman, Crossing Tender, Drawbridge Tender

Group 2 Fireman (if not qualified as an engineer)

Safety Hazard Potential	High
Physical Demands	Low
Exposure to Weather	Low

The gate tender or crossing watchman stationed at a public crossing of a railroad track is responsible for protecting vehicular and pedestrian traffic during the passage of a train.

The post for the gate tender or watchman may, or may not, be equipped with colored lights and/or bells to indicate the approach of trains.

Tasks

1. To maintain a constant watch for the approach of trains from either direction without depending solely on indicator lights, bells, or the engineman's whistle for the grade crossing.
2. To stop highway and pedestrian traffic from crossing the tracks upon the approach of a train, either by lowering the gates if so equipped, or by using a "stop" disk by day or a red light at night.
3. To inspect passing trains for defects, being prepared to give a stop sign to the crew if necessary.
4. To record necessary data in case of an accident.
5. To inspect crossing gate lights, if gates are provided.
6. To stop an approaching train, if necessary.