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**Federal Railroad
Administration**

Understanding How Train Dispatchers Manage and Control Trains

Results of a Cognitive Task Analysis

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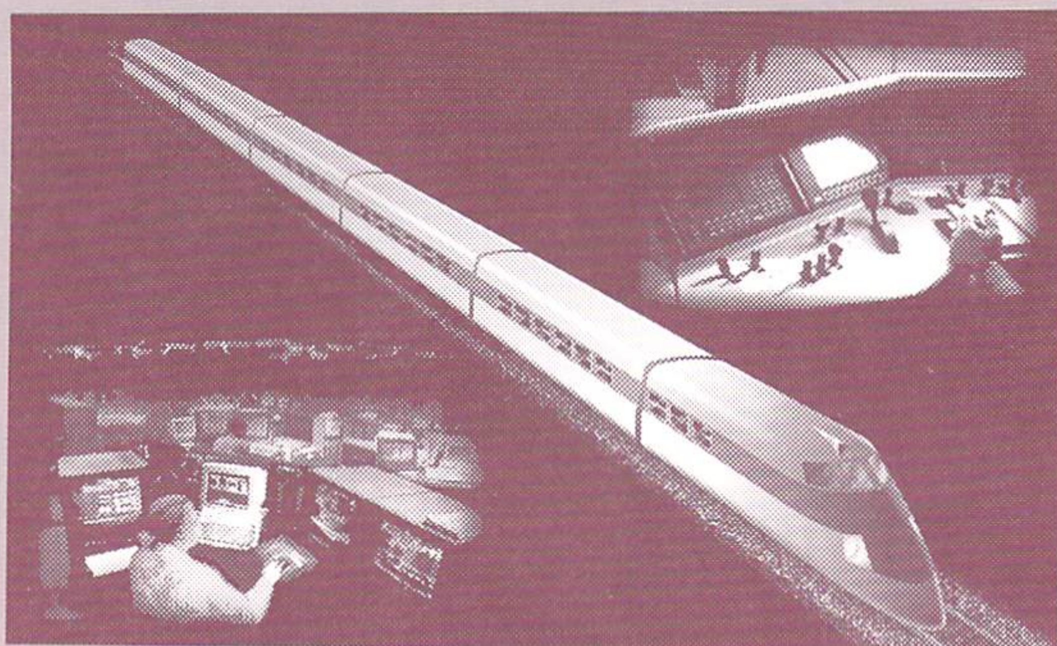

Human Factors in Railroad Operations

DOT/FRA/ORD-01/02

Final Report
May 2001

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13. ABSTRACT (Maximum 200 words)

This report documents the results of a Cognitive Task Analysis that examined how experienced railroad dispatchers manage and schedule trains in today's environment. The objective was to understand the cognitive demands placed on railroad dispatchers and the strategies that experienced dispatchers have developed in response to those demands, as an input to guide development and design of digital communication systems and advanced information displays. A hybrid methodology was used that combined field observations at two railroad dispatch centers (one that primarily handles passenger trains and one that primarily handles freight trains) with structured interviews of experienced railroad dispatchers.

The results reveal that dispatching is a cognitively demanding task. Dispatchers have developed a variety of strategies that smooth the way for trains to pass through territories safely and efficiently and satisfy the multiple demands placed on track use. These include techniques to off-load memory requirements, extract information about train movement and track activity to support anticipation and planning, take advantage of windows of opportunity to satisfy the multiple demands placed on track use, and level workload. Many of these strategies depend heavily on communication and coordination among individuals distributed across time and space.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0			1			2		3			4		5
Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Preface

This report documents the result of a Cognitive Task Analysis (CTA) that was conducted to gain an understanding of the cognitive activities that are involved in railroad dispatching. The purpose of the preliminary CTA was to examine how experienced railroad dispatchers manage and schedule trains in today's environment. The objective was to gain insight into the cognitive demands placed on railroad dispatchers and the strategies they have developed in response to those demands as input to guide the development and design of new computer-based systems and safety-related decision aids.

One of the objectives of the CTA was to provide input to an ongoing collaborative program between Massachusetts Institute of Technology (MIT) and the Volpe National Transportation Systems Center (Volpe Center) that is investigating the application of "data link" communications systems to the railroad environment. While data link has the potential to increase safety, and improve productivity and efficiency of railroad operations, it is important to clearly understand how this technology can affect human performance.

The work was sponsored by the Federal Railroad Administration's (FRA) Office of Research and Development.

Acknowledgement

The authors would like to thank Claire Orth and Thomas Raslear from the FRA's Office of Research and Development for their support and guidance. The work was performed as part of a collaborative effort between the Volpe Center and MIT.

The authors would like to acknowledge the technical contributions of Michael Coplen from the FRA and Nora Katz-Rhoads from the Volpe Center, who provided invaluable insights into the operations of railroad Dispatch Centers and helped champion and shape the CTA that was performed. We would also like to thank Tom Sheridan of MIT for his support of the project.

The authors would especially like to thank Steve Jones of Amtrak and Allan Fisher of Conrail for providing permission and arranging for us to perform observations at the railroad Dispatch Centers. We would also like to thank the railroad dispatchers whom we observed and interviewed, for their patience and generosity in sharing their time and knowledge with us.

We would also like to thank Glenn Underwood, Manager of Train Operations at Amtrak, Donald Sussman of the Volpe Center, and Steven Ditmeyer of the FRA for reviewing an earlier draft of this report and suggesting revisions to improve the accuracy and clarity of descriptions of railroad operations.

Finally, we would like to thank John Pollard of the Volpe Center for sharing his knowledge and enthusiasm of railroad operations and helping us to obtain photographs of one of the railroad Dispatch Centers.

Table of Contents

Section **Page**

Table of Contents (cont.)

List of Figures

List of Tables

Glossary

Automatic Block System (ABS). A block signal system wherein the use of each block is governed by an automatic block signal, cab signal, or both.

Block. A length of track with defined limits on which train movements are governed by block signals, cab signals, or Form D.

Block Operator. A field operator who manually controls signals and interlockings for a block.

Centralized Traffic Control (CTC). A signal system that allows the dispatcher to know which blocks are occupied by trains and roadway workers and to control switches and signals remotely from the Dispatch Center.

Cognitive Task Analysis (CTA). Analysis of the cognitive demands of a complex task. This includes the knowledge, mental processes, and decisions that are required to perform the task. The goals of the CTA are (1) to identify what factors contribute to cognitive performance difficulty; (2) to uncover the knowledge and skills that expert practitioners have developed to cope with task demands; and (3) to specify ways to improve individual and team cognitive performance in a domain through new forms of training, user interfaces, or decision aids.

Consist. The makeup of a train, including locomotives and cars, and described by its locomotive power, tonnage, initial number, and type of each car, and location and type of hazardous materials.

Crossover. A combination of two switches connecting two adjacent tracks. When lined, this switch combination allows movements to cross from one track to the other.

Dark territory. A section of track that is unsignaled. In dark territory, the dispatcher does not get automatic indication of the location of the train, nor does the train get automatic signals allowing movement through the territory.

Data Link. A digital communication capability that provides a means for moving information to and from different locations. In the railroad environment, this includes the control center, trains, and other entities on the track (e.g., track vehicles, maintenance-of-way personnel). With data link communications, the information is digitally coded and messages can be discretely addressed to individual or multiple recipients. An advantage of digital technology is that it increases the flexibility of the information presentation media. Information can be presented visually (e.g., as text or graphics) or acoustically (as a voice message).

Extra Train. A train not designated by a timetable schedule.

Form D. A track use authority form that is issued by a railroad dispatcher. A Form D contains written authorization(s), restriction(s), or instruction(s) issued by the Dispatcher to specified individuals. The Form D permits trains and other track users to occupy specific segments of track identified by the railroad dispatcher.

Foul time. Time during which track is temporarily obstructed for work on or around the track. The term "foul time" is used by railroads that follow the NORAC operating rules. Other railroads use other terms (e.g., track and time) to refer to the same condition.

Interlocking. A configuration of switches and signals interconnected to direct trains along different routes, the limits of which are governed by interlocking signals.

Intermodal Train. A train carrying shipping containers or highway trailers.

Maintenance-of-Way (MOW). On-track maintenance for repairing, testing, and inspecting track.

NORAC. Northeast Operating Rules Advisory Committee.

Operating Rules. A book of rules that govern a particular railroad's operating procedures and practices.

Siding. A track adjacent to a main track and used for meeting and passing trains, or for the parking and storage of cars.

Shunt. Activate automatic block or interlocking signals when present on track.

Special Train. A type of extra train that may have a high profile resulting in special priority. Examples include test trains, trains hired by private parties, trains of dignitaries, and circus trains.

Track and Time. Time during which track is temporarily obstructed for work on or around the track. Different railroads may use other terms (e.g., foul time) to refer to the same thing.

Track Car. Equipment, other than trains, operated on a track for inspection or maintenance. Track cars may not shunt track circuits.

Executive Summary

Good dispatching is critical to both the safety and efficiency of railroad operations. Railroad dispatchers are responsible for allocating and assigning track use, ensuring that trains are routed safely and efficiently, and ensuring the safety of personnel working on and around railroad track. These are cognitively complex tasks that require integrating multiple sources of information (e.g., information from train schedules, computer displays of current track state, radio communication with various personnel such as locomotive engineers, and in some cases (computer-aided dispatching systems); projecting into the future (e.g., estimating when the train will arrive); and balancing multiple demands placed on track use (e.g., balancing the need for maintenance-of-way (MOW) workers to have time to work on the track with the need to make sure that the track will be clear when a train is anticipated to arrive).

As part of its efforts to investigate the safety implications of applying emerging technologies to railroad operations, the Federal Railroad Administration's (FRA's) Office of Research and Development sponsored a preliminary Cognitive Task Analysis (CTA) to examine how experienced railroad dispatchers manage and schedule trains. The objective was to conduct a small-scale study that (1) would demonstrate the methods and value of CTA, and (2) would produce preliminary results that would serve as a basis for guiding future, more focused, research and development programs aimed at improving displays, methods of communication and other computer-aided dispatching systems.

A CTA is an analysis of the cognitive demands of a complex task. This includes the knowledge, mental processes, and decisions that are required to perform the task. The goals of CTA are (1) to identify what factors contribute to cognitive performance difficulty; (2) to uncover the knowledge and skills that expert practitioners have developed to cope with task demands; and (3) to specify ways to improve individual and team cognitive performance in a domain through new forms of training, user interfaces, or decision aids.

Study Objectives and Approach

The purpose of the CTA was to examine how experienced dispatchers manage and schedule trains in today's environment. The intent was to identify (1) cognitive activities that could be supported more effectively through the introduction of new technology as well as (2) features of the existing environment that contribute to effective performance that should be preserved when transitioning to new technologies. One of the particular objectives of the CTA was to provide input to a collaborative program between MIT and the Volpe National Transportation Systems Center (Volpe Center) that is investigating the application of "data link" communications systems to the railroad environment.

Data link communications networks provide a means for moving digitally coded information to and from different locations. In the railroad environment, this includes dispatch control centers, trains, other entities on the track (e.g., track vehicles, MOW personnel), passenger stations, and maintenance facilities among others. It is envisioned that data link communications will replace or supplement many of today's routine voice communications that occur over radio with digital messages (Bureau of Transportation Statistics, 2000; Ditmeyer and Smith, 1993; Vanderhorst, 1990).

Data link communications offer a number of advantages over voice radio communication. Data link results in increased bandwidth and reliability of information transmission. In addition, data link affords a great deal of flexibility with respect to when, to whom, and how messages are presented. With data link communications, messages can be discretely addressed to a single individual or broadcast to multiple recipients. Information can be presented visually (e.g., as text or graphics) or acoustically (e.g., as audio or voice). The communication can involve real-time interaction among the parties (synchronous communication) or it can be sent at one point in time and accessed at a later point in time (asynchronous communication). This contrasts with voice radio communication that is limited to real-time voice communication that is broadcast to everyone within range of the transmission.

One of the objectives of the CTA study was to examine how voice radio communication is used in today's environment in order to provide recommendations for how the flexibility afforded by data link technology should be deployed to improve communication efficiency and effectiveness.

The preliminary CTA used a hybrid methodology that combined field observations at Dispatch Centers with structured interviews of experienced dispatchers to build and progressively refine an understanding of the demands placed on dispatchers and the knowledge and strategies that experienced dispatchers have developed to respond to those demands.

The preliminary CTA was conducted in four phases. The CTA began with 2 days of observing dispatchers as they went about their job in their actual work environment in a railroad Dispatch Center that primarily handled passenger trains (Phase 1). Phase 2 consisted of structured interviews with experienced dispatchers and related personnel from the railroad Dispatch Center where the first field observations were held. Topics covered in the interviews included:

- Complicating factors that made track management and train routing difficult.
- The strategies that they have developed to facilitate performance and to maintain the big picture.
- Issues in training new dispatchers.
- Suggestions for improved communication systems and/or computerized support systems.

Phase 3 involved field observations at a second Dispatch Center that primarily handled freight trains. The objective of this phase was to assess the generality of the results obtained at the first Dispatch Center. The fourth phase involved a second set of field observations at the same Dispatch Center observed during Phase 1. The objective was to verify and expand on the results obtained in the previous three phases.

In general, the results from each phase confirmed and extended the results from the previous phase. This was true both with respect to the field observation and interview phases at Dispatcher Center 1 as well as the field observations that were performed at Dispatcher Center 2.

Study Results: What Makes Railroad Dispatching Difficult?

The results reveal that dispatching is a complex, cognitively demanding task. Successful performance depends on the ability of dispatchers to monitor train movement beyond their territory, anticipate delays, balance multiple demands placed on track use, and make rapid decisions. This requires keeping track of where trains are, whether they will reach destination points (meets, stations) on time or will be delayed, and how long the delays will be.

Another source of complexity is heavy attention and communication demands. At any given time, the dispatcher may need to monitor multiple activities in different parts of his territory at a time. The fact that the total set of things to keep track of is not always displayed can exacerbate the problem and increase the likelihood that something is forgotten.

Traffic over voice radio places particularly high attention demands. Communications include the need to:

- Answer requests for, and issue train movement and track use authorization to locomotive engineers, MOW staff, etc.
- Inform locomotive engineers whether there are any updates to speed bulletins or other messages.
- Find out the status of trains – where they are, why they are delayed.
- Exchange information regarding rail track and signal conditions (e.g., broken rail, malfunctioning signals, obstacles on the track, trespassers).
- Coordinate with train masters and yard masters.
- Coordinate with emergency response personnel (e.g., police, fire, and ambulance) in accident situations.

In summary, there are a number of factors that contribute to the difficulty of the dispatcher's job. These include:

- Demands on track use are high and the margin for flexibility can be low. Trains need to be within 5 minutes of schedule and there are limited routing options available.
- Predicting when a train will arrive or the length of delay can be difficult because it requires keeping track of the progress of multiple trains, some outside the area controlled by the Dispatch Center, as this requires knowledge and consideration of multiple factors that can influence train speed.
- Workload, attention, and memory demands are high.
- Attention demands associated with monitoring the radio channels and responding to radio requests, which are particularly high.

Results: Expert Strategies to Meet Task Demands

Dispatchers have developed a number of strategies that enable trains to pass through territories more efficiently, and satisfy the multiple demands that are placed on track use. Experienced dispatchers have developed strategies that allow them to anticipate requirements for changes to schedules and planned meets to have time to take compensatory action. They monitor the wall panel display, consult with other dispatchers, and "listen for" information on the radio that will allow them to track progress of train movement and get early indication of the need for re-planning.

Dispatchers have developed a number of strategies to (1) off-load memory requirements; (2) extract information about train movement and track activity to support anticipation and planning ahead; (3) act proactively, taking advantage of windows of opportunity to satisfy the multiple demands placed on track use; and (4) level workload.

Many of these strategies depend on communication and coordination among individuals distributed across time and space. This includes coordination among dispatchers managing abutting territories within a Dispatch Center as well as coordination among the various crafts within a railroad (e.g., locomotive engineers, train masters, dispatchers, and MOW personnel).

This report describes the strategies employed by experienced dispatchers in detail. The strategies illustrate the types of skills required for the job of dispatcher. These need to be considered in the design of training programs as well as new displays and decision aids. Awareness of dispatcher strategies is important for designers of new aiding technologies from two perspectives. First, the strategies may indicate problems in the current dispatching environment that dispatchers are compensating for, and may suggest ideas for new aids that eliminate the need for compensatory strategies. Second, in introducing technologies, designers need to be careful not to inadvertently create conditions that can disrupt the ability of dispatchers to utilize effective strategies.

Implications for Advanced Displays and Decision Aids

The report documents a number of suggestions (many offered by the dispatchers themselves) for new information, visualizations, and decision aids to support dispatcher decision-making. These suggestions fall into several categories:

- Ways to enhance the ability of dispatchers to track train progress and anticipate train delays.
- Ways to help dispatchers more readily access the detailed information that affect train routing and track use decisions.
- Ways to help dispatchers visualize the physical layout of the track and surrounding geography.
- Planning aids for dynamically identifying train routes and establishing meets and passes.

Dispatchers believed that more accurate information on train location and train movement would be useful. This would help dispatchers better anticipate train delays, as well as manage track more efficiently.

Another suggestion for improved performance is to shift paper resources to electronic media. Currently, many information sources (e.g., operating rules, train timetables, speed bulletins, track outage schedules, policy updates, telephone numbers, contents of the desk file) exist only in paper form and are dispersed in many separate documents. As a result, dispatchers cannot easily refer to these documents in making real-time dispatch decisions and must rely on their memory of the document contents. If these documents were converted to electronic form and cross-indexed in such a way that information relevant to particular dispatch decisions could more readily be accessed, it would better support dispatch decisions.

Another recommendation is to provide dispatchers with more accurate visualizations of the physical track and surrounding geography. Many dispatch decisions depend on having accurate knowledge of the physical layout of the track and surrounding geography. Dispatchers stressed that this is critical to maintaining the safety of personnel working on the track as well as enabling dispatchers to effectively coordinate response in emergencies. Currently, the computer displays of the track are schematic representations that are neither sufficiently accurate nor detailed to support dispatchers in visualizing the physical track. It would be useful to add displays to the computer system that provide more accurate visualizations of the track and surrounding streets.

Dispatchers would also benefit from decision aids that would help them manage unplanned events more effectively. As the CTA revealed, unplanned events pose dispatchers the most difficulty. A real-time planning aid would be very useful.

Burlington Northern Railroad pioneered work on real time planning systems (Ditmeyer and Smith, 1993). The real time planning system included two online control systems, the Tactical Traffic Planner (TTP) and the Strategic Traffic Planner (STP). The TTP generates plans for meeting and passing trains on a dispatcher's territory, and supports real-time replanning, adjusting meet and pass locations to recover undesired lateness. The STP operates at a more "strategic" control level, establishing train priorities and schedule targets.

Research on planning and scheduling aids for railroad dispatching is progressing in promising directions. For example, the FRA is currently funding research to develop graphic visualization aids to support dispatchers in routing trains and planning and scheduling MOW work.

Implications for Data Link Technology

The voice radio channels are now overloaded and there is a need to off-load communication onto other media. Further, there was indication that voice radio is not well suited to some of the types of communication that are now conducted on it. For example, long dialogues intended to convey detailed information such as exact location are better suited to data link communications and would benefit from the availability of visual graphics to provide a common frame of reference and avoid misunderstandings. Similarly, reading aloud and then repeating back complicated movement authorization forms (Form D) ties up the communication channel, the dispatcher and the person receiving the Form D longer than necessary, and is error prone. These results are consistent with the findings of Vanderhorst (1990) who studied dispatcher communication in a Dispatch Center that primarily handled freight operations.

Data link technology provides a vehicle for taking information that is now passed over the voice radio and transferring it over data link instead (Ditmeyer and Smith, 1993). This means that information that is currently communicated orally over the radio could be presented visually on a computer display instead. This has clear benefits for certain types of information such as movement authorization forms and blanket orders such as speed summary bulletins and supplementary bulletins.

Different types of communication have different presentation requirements. The report discusses attributes on which presentation media can differ that can affect human cognition and collaboration. These requirements should be considered in assessing what communication to shift from voice radio, and the most appropriate mode of presentation for that type of communication.

Messages that involve detailed instruction and precise location information, such as movement authorization forms are best communicated via a private channel with the information presented visually. In contrast, messages that involve alerts to hazards on the track (e.g., obstacles, broken rails, trespassers) are more appropriately communicated on a broadcast channel to most efficiently reach the most number of individuals that are potentially affected. These conclusions are consistent with the findings of Vanderhorst (1990). They are supported by a recent study that compared discreet recipient and "broadcast" versions of data link systems in a simulated dispatching task (Malsch, Sheridan, and Multer, in press).

In spite of the fact that "party line" communication is often noisy and congested, the dispatchers value the "broadcast" information the line provides. This information provides a shared frame of reference and allows dispatchers and others working on the railroad to anticipate situations and act proactively. Dispatchers reported that they routinely "listen for" information on the radio channel that is not directly addressed to them but provides important clues to potential delays, problems, or a need for assistance. It is important that any new communication system preserve information now provided by the party line that is critical to safety or productivity. However, it is not implied that any new system preserve the party line information in it's entirety; the information to be preserved should be a function of the operation. The finding that the party line is considered important in today's operations should be viewed as an indication of the kinds of information that dispatchers need to be effective. The fact that dispatchers are currently extracting this information by overhearing conversations is symptomatic of the paucity of information provided to dispatchers in today's environment. The information that dispatchers were able to extract by "listening" to communication that was not explicitly directed at them, provide cues to the kinds of information dispatchers need. This knowledge can be used to guide the design of data link systems. Specific guidance is provided in the report.

Implications for Selection and Training

The report documents a variety of cognitive skills that experienced dispatchers have developed that enable them to cope with the demands of dispatching. Currently, these cognitive skills are expected to be learned from experienced dispatchers in apprenticeship mode. Apprenticeship, while an effective approach to training, is not necessarily the most efficient way to build up the knowledge and skills required to make effective dispatch decisions. An apprenticeship approach to training is particularly challenging in environments such as dispatching where the real-time workload demands are high, making it difficult for experienced dispatchers to provide the level of explanation for their decision that is required to support developing equivalent decision-making skills in trainees.

One approach is to develop simulator-based training to bring new trainees more rapidly up to a high level of performance. Currently, Dispatch Centers utilize training simulators to familiarize new dispatchers with the mechanics of routing trains using the computer CRT displays. Simulator training could be expanded to provide more practice on the cognitive and decision-making skills required to handle complex dispatching situations. Examples of complex situations that could be presented in a simulator include cases where there are switch failures, extra trains, trains with long consists, train derailments, etc.

Examples of cognitive skills that need to be developed that might benefit from simulator training include:

- Strategies to support anticipation.
- Strategies to maintain broad awareness.
- Cooperative strategies to maximize route efficiency across dispatch territories.
- Strategies for anticipating problems and planning contingencies.
- Strategies for leveling workload.
- Strategies for performing multiple tasks in parallel.

Training could be more focused on building up these specific cognitive skills and expert strategies. The skills could be developed by providing progressive experience and practice in handling complex scenarios that require applying those skills in a simulator environment.

Insights into the cognitive skills that underlie expert dispatch performance also may be useful for developing objective tests that, in combination with the types of interviews currently conducted, would result in an improved dispatcher selection process.

1. Introduction

A critical function to both the safety and efficiency of railroad operations is the railroad dispatcher's job. The railroad dispatcher is responsible for managing track use, ensuring that trains are routed safely and efficiently, and ensuring the safety of personnel working on and around railroad track. These activities are cognitively complex tasks that require integrating multiple sources of information. These sources include information from train schedules, computer displays of current track state, voice radio communication with various personnel such as locomotive engineers, and in some cases computer-aided dispatching systems. The dispatcher's tasks include projecting into the future (e.g., estimating when the train will arrive) and balancing the multiple demands placed on track use (e.g., balancing the need for maintenance-of-way (MOW) workers to have time to work on the track with the need to make sure that the track will be clear when a train is anticipated to arrive).

As part of its efforts to investigate the safety implications of applying emerging technologies to railroad operations, the Federal Railroad Administration's Office of Research and Development sponsored a preliminary Cognitive Task Analysis (CTA) to gain an understanding of the cognitive activities that are involved in railroad dispatching. This report documents the results of the preliminary CTA.

The purpose of the preliminary CTA was to examine how experienced dispatchers manage and schedule trains in today's environment. The objective was to gain insight into the cognitive demands placed on dispatchers and the strategies they have developed in response to those demands as input to guide the development and design of new computer-based systems and safety-related decision aids such as digital "data link" communication systems and advanced information displays. The intent was to identify (1) cognitive activities that could be supported more effectively through the introduction of new technology as well as (2) features of the existing environment that contribute to effective performance that should be preserved when transitioning to new technologies.

A CTA can provide critical inputs necessary to the development and enhancement of computer-based information systems and safety-related decisions aids in both early and later stages of development. Applications include the design of innovative information displays, the implementation of new technology, and the development of new training programs. One of the particular objectives of the preliminary CTA was to provide input to an ongoing collaborative program between Massachusetts Institute of Technology (MIT) and the Volpe National Transportation Systems Center (Volpe Center) that is investigating the application of "data link" communications systems to the railroad environment.

Data link communications networks provide a means for moving digitally coded information to and from different locations. In the railroad environment, this includes dispatch control centers, trains, other entities on the track (e.g., track vehicles, maintenance-of-way personnel), passenger stations, and maintenance facilities among others. It is envisioned that data link communications will replace or supplement many of today's routine voice communications that occur over radio with digital messages (Bureau of Transportation Statistics; Ditmeyer and Smith, 1993; Vanderhorst, 1990).

Data link technology will increase the capacity of available communications circuits and frequencies. Data link communication can utilize radio frequencies to communicate to and from mobile entities, and can use a variety of transmission media to communicate between fixed facilities (e.g., microwave radio, fiber optic cable, buried copper cable, and communication satellites).

Data link communication offers a number of advantages over voice radio communication. Data link results in increased bandwidth and reliability of information transmission. Data link also offers greater flexibility in communication. With voice radio, messages are broadcast. They can be overheard by anyone within range of the transmission. With data link communications, messages can be discretely addressed to a single individual or broadcast to multiple recipients. Digital technology also increases the flexibility of the information presentation media. Information can be presented visually (e.g., as text or graphics) or acoustically (e.g., as audio or voice).[1] This contrasts with voice radio where the information is necessarily presented aurally.

Data link communication also offers flexibility with respect to when a message is received relative to when it is sent. With voice radio, communication requires that the sender and receiver be available at the same time. Data link technology allows for both synchronous and asynchronous communication. As with voice radio, data link allows for real-time interactive communication (synchronous communication). It also allows for asynchronous communication where the sender inputs information at one point in time, and the message is stored and made available for the receiver to obtain at a later point in time.

Data link technology offers greater flexibility than voice radio along several dimensions. One of the objectives of the CTA study was to examine how voice radio communication is used in today's environment, in order to provide recommendations for how the flexibility afforded by data link technology should be deployed to improve communication efficiency and effectiveness.

1.1 Cognitive Task Analysis Goals and Methods

CTA methods have grown out of the need to explicitly identify and take into account the cognitive requirements inherent in performing complex tasks. This includes the knowledge, mental processes, and decisions that are required to perform a task. CTA contrasts with traditional task analysis techniques that are often used to develop job performance aids or training programs. Traditional task analyses break tasks down into a series of external, observable behaviors. For certain kinds of tasks that involve little decision-making requirements (e.g., assembly-line jobs) traditional task analysis methods work well. However, as the routine aspects of jobs have become more automated, there has been a growing appreciation that many safety-critical jobs (e.g., air traffic controller; aircraft pilot; power plant operator; electronics troubleshooter; operating room staff) involve complex knowledge and cognitive activities that cannot be observed. Examples of cognitive activities include monitoring, situation assessment, planning, deciding, anticipating, and prioritizing.

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[1] The range of presentation media that can be used with digital data are extensive. In addition to visual and auditory displays, it is possible to consider tactile displays (cf. Sklar and Sarter, 1999).

Since at least the early 1980's, the desire to enhance human performance in cognitive work has led researchers to develop techniques for CTA, either as the basis for training systems (e.g., Hall, Gott and Pokorny, 1995) or as the basis for online computer-based support systems (Hollnagel and Woods, 1983; Roth and Woods, 1988; Woods and Hollnagel, 1987). A variety of specific techniques drawing from basic principles and methods of Cognitive Psychology has been developed (Cooke, 1994; Militello, Hutton, Pliske, Knight and Klein, 1997; Potter, Roth, Woods and Elm, 1997; 1998; Roth and Woods, 1989). These include structured interview techniques, critical incident methods, field study methodologies, and simulation-based methods.

The goal of CTA is to specify ways to improve individual and team performance in a domain (be it through new forms of training, user interfaces, or decision aids). From this perspective, CTA is best thought of as a process for uncovering the cognitive activities that are required for task performance in a domain and identifying opportunities to improve performance through better support of these cognitive activities.

Figure 1, taken from Potter, Roth, Woods, and Elm (1998), provides an overview of the CTA process. In performing CTA, two mutually reinforcing perspectives need to be considered (as depicted by the two "dimensions" on the ordinate axis in Figure 1). One perspective focuses on the *fundamental characteristics of the domain* and the cognitive demands they impose. The focus is on understanding the way the world works today and what factors contribute to making practitioner performance challenging. Understanding domain characteristics is important for several reasons. One reason is that it provides a framework for interpreting practitioner performance (e.g., Why do experts utilize the strategies they do? To what complexities in the domain are they responding? Why do less experienced practitioners perform less well? To what constraints in the domain are they less sensitive?). A second reason is that it helps define the requirements for effective support (e.g., What aspects of performance could use support? What are the hard cases where support could really be useful?). A third reason is that understanding task demands helps define the bounds of feasible support (e.g., What technologies can be brought to bear to deal with the complexities inherent in the domain? Which aspects of the domain tasks are amenable to support, and which are beyond the capabilities of current technologies?).

The second perspective focuses on how today's practitioners respond to the demands of the domain. Understanding the knowledge and strategies that expert practitioners have developed in response to the domain demands provides a second window for uncovering what makes today's world hard and what are effective strategies for dealing with domain demands. These strategies can be captured and transmitted directly to less experienced practitioners (e.g., through training systems) or they can provide ideas for more effective support systems that would eliminate the need for these compensating strategies. Examining the performance of average and less experienced practitioners is also important as it can reveal where the needs for support are.

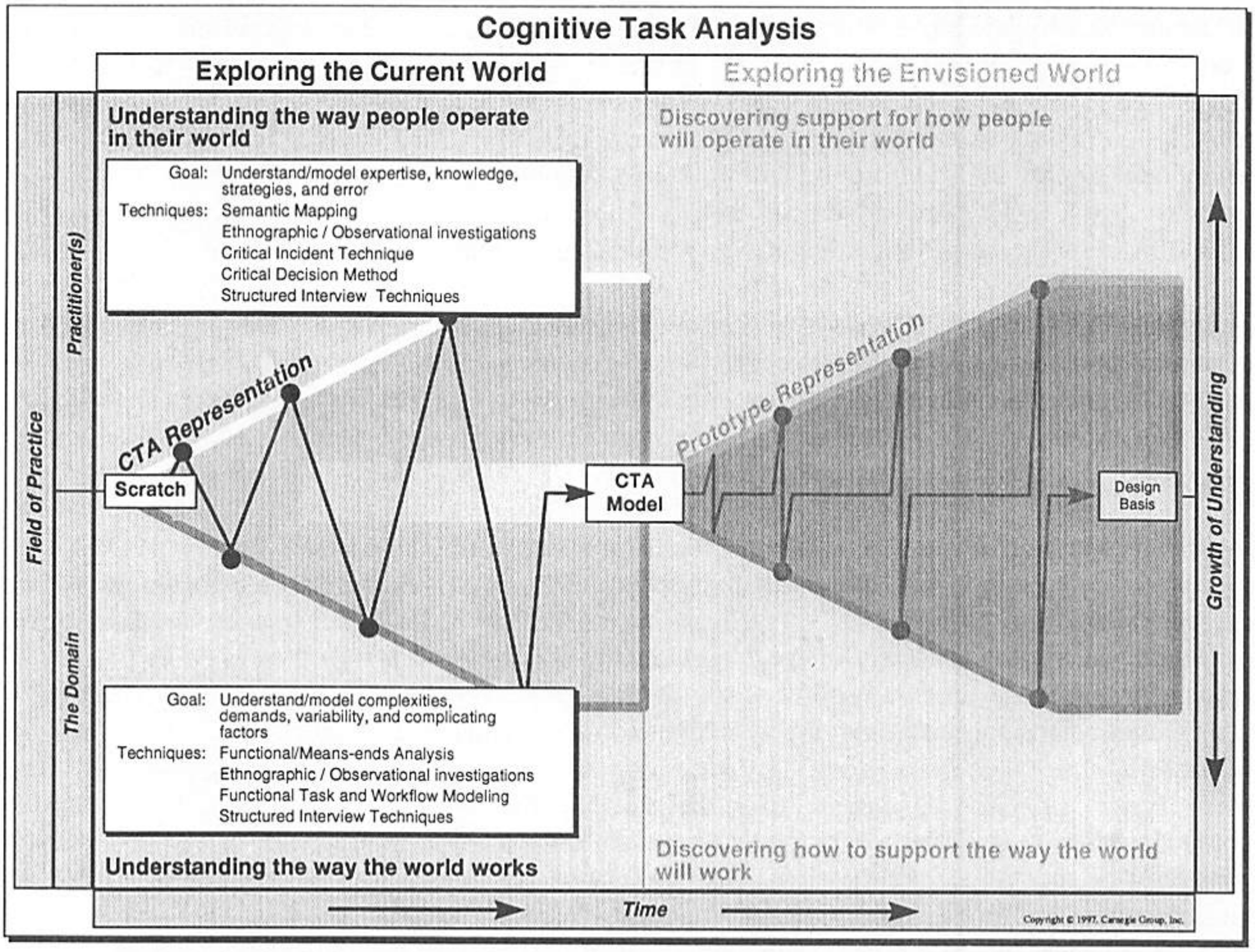

Figure 1. Overview of an Integrated Approach to CTA (Reprinted from Potter, Roth Woods and Elm, 1998).

CTA is an iterative process focused on understanding both the *cognitive demands of the domain* and the knowledge and cognitive strategies of *domain practitioners.* The left side of the figure depicts CTA activities intended to understand how domain practitioners operate in the *current work environment.* Results of CTA activities are represented by the nodes along the activity trajectory. The right side of the figure emphasizes that the analysis process continues into the design/prototype development phase. The results of the analysis of the current work environment (the output of the left side) generate hypotheses for ways to improve performance (*the envisioned world*). The hypotheses are embodied in design prototypes, which are used in turn to discover additional requirements for useful support.

CTA is fundamentally an opportunistic bootstrap process. The selection and timing of particular techniques to be deployed will depend on the detailed constraints and pragmatics of the particular domain being addressed. One starts from an initial base of knowledge regarding the domain and how practitioners function within it (often very limited). One then uses a number of CTA techniques to expand on, enrich the base understanding, and evolve a CTA model from which ideas for improved support can be generated.

The phrase "bootstrapping process" is used to emphasize the fact that the process builds on itself. Each step taken expands the base of knowledge providing the opportunity to take the next step. Making progress on one line of inquiry (understanding one aspect of the field of practice) creates the room to make progress on another. For example, one might start by reading available documents that provide background on the field of practice (e.g., training manuals, procedures). The knowledge gained will raise new questions or hypotheses to pursue that can then be addressed in interviews with domain experts. It will also provide the background for interpreting what the experts say. In turn, the results of interviews may point to complicating factors in the domain that place heavy cognitive demands and opportunities for error. This information may provide the necessary background to create scenarios to be used to observe practitioner performance under simulated conditions or to look for confirming example cases or interpret observations in naturalistic field studies.

In practice, the CTA process generally requires the use of multiple converging techniques that include techniques that focus on understanding the domain demands as well as techniques that focus on understanding the knowledge and strategies of domain practitioners. The particular set of techniques selected will be strongly determined by the pragmatics of the specific local conditions. For example, access to domain practitioners is often limited. In that case, other sources of domain knowledge (e.g. written documents) should be maximally exploited before turning to domain experts. In some cases, observing domain experts in actual work practice (using ethnographic methods or simulator studies) may be impractical, in those cases using structured interview techniques (such as concept mapping) and critical incident analysis may be the most practical methods available.

Roth, Mumaw, Vicente, and Burns (1997) provides a recent example of a CTA that employed multiple converging techniques in a bootstrap approach to understanding nuclear power plant operator monitoring during normal operations. The study began with limited, opportunistic, field observations of operator crews during their regular shifts. One of the authors sat in the room observing the operators and casually asking questions and eliciting "stories" of past cases where complicating factors made monitoring hard, and the strategies the operators had evolved to facilitate monitoring. The results were then documented in a report, which was passed on to the operator crews for review and comment. The operator comments were used to correct misunderstandings and provide additional examples of the classes of factors that made monitoring hard and monitoring strategies developed by operators. The accuracy and generality of the understanding developed at that point and was then further tested by (1) observing a larger set of operator crews at the same plant, and (2) observing and interviewing operator crews at two additional plants that had progressively more advanced computer technology in the control room. The results further broadened the level of understanding. It made salient findings which were specific to particular plant technologies and which were applicable across technologies. The results were captured in a model of operator monitoring during normal operations that stressed the knowledge-driven, selective-attention, aspect of operator monitoring and laid out the classes of facilitating strategies that operators have developed to facilitate monitoring and compensate for limitations in available control room technology. The model in turn was used to suggest concepts for improvements to control room interfaces to support operator monitoring more effectively.

The right side of Figure 1 emphasizes that in a complete CTA, the analysis process continues into the design/prototype development phase. The results of the analysis of the current work environment (the output of the left side) generate *initial hypotheses* for ways to improve performance. The hypotheses are embodied in design prototypes, which are used in turn to discover additional requirements for useful support (Woods, in press).

1.2 Scope, Objectives, and Approach

This report documents the results of a preliminary CTA that was conducted to examine how experienced dispatchers manage and schedule trains in today's environment. The preliminary CTA was not intended to be comprehensive or fine-grained. The objective was to provide a first, broad-based overview of the railroad dispatching environment, the cognitive demands placed on dispatchers, and the strategies that experienced dispatchers have developed in response to those demands. The objective was to conduct a small-scale study that (1) would demonstrate the methods and value of CTA analyses, and (2) would produce preliminary results that would serve as a basis for guiding future, more focused, research and development programs aimed at improving dispatching.

Reinach, Gertler, and Kuehn (1998) provide a good overview of railroad dispatcher job functions. They divide the dispatcher job into four functions: planning, controlling track use, managing unplanned and emergency events, and performing required record keeping. The focus of the preliminary CTA was on how dispatchers plan and control track use. It particularly focused on how dispatchers manage unplanned events that affect control of track use.

The preliminary CTA had two primary objectives:

- Provide an overview of dispatcher decision-making activities, sources of complexity, and knowledge and skills that underlie expertise as a basis for identifying areas of opportunity for improvement in performance via changes in training, practice, or introduction of new technology.

- Focus on characterizing current communication practice between dispatchers and other personnel that impact train scheduling decisions (e.g., locomotive engineers, train conductors, MOW personnel, chief dispatcher) as input to development of interface design concepts as part of the digital data link communications systems program that is investigating new concepts for off-loading voice radio-based communication onto alternative media.

Questions addressed included:

- What decisions are the dispatchers now making?
- What is the input to those decisions and what is the output?
- What information is currently communicated/shared between dispatchers and other train personnel, and what information is not currently shared but would be useful to share?

The CTA used a hybrid methodology that combined ethnographic field observations at Dispatch Centers with structured interviews of experienced dispatchers to build and progressively refine an understanding of the demands placed on dispatchers and the knowledge and strategies that experienced dispatchers have developed to respond to those demands.

The CTA was conducted in four phases. The CTA began with 2 days of observing dispatchers as they went about their job in their actual work environment in a railroad Dispatch Center that primarily handled passenger trains (Phase 1). Two observers participated. Each observer sat next to a dispatcher and observed the communications the dispatcher engaged in, and the train routing and track management decisions made. The observer asked the dispatchers questions when invited to by the dispatcher during low workload periods. Questions were guided by a checklist of topics to be covered that was generated ahead of time.

Phase 2 consisted of structured interviews with experienced dispatchers and related personnel from the railroad Dispatch Center where the first field observations were held. Three experienced dispatchers were interviewed. Topics covered in the interviews included:

- Complicating factors that made track management and train routing difficult.
- The strategies that they have developed to facilitate performance and maintain the big picture.
- The communication systems and how they used them.
- The computer systems in the Dispatch Center and how they use them.
- Issues in training new dispatchers.
- Suggestions for improved communication systems and/or computerized support systems.

In addition to interviews of dispatchers, an interview was held with the superintendent of the railroad Dispatch Center to gain management perspective on dispatcher activities, challenges, and opportunities for improvement.

An interview also was conducted with a commuter locomotive engineer. The interview was conducted in the engine cab during a scheduled run. The objective was to examine the voice radio communication and train routing decision from the perspective of the locomotive engineer to look for convergence and/or divergence of beliefs and opinions.

Phase 3 involved field observations at a second Dispatch Center that primarily handled freight trains. Two observers visited a second Dispatch Center for a day where they observed and interviewed dispatchers as they performed their regular dispatching duties. The objective of this phase was to assess the generality of the results obtained at the first Dispatch Center.

The fourth phase involved a second set of field observations at the same Dispatch Center observed during Phase 1. This phase involved 2 days of additional observations of dispatchers as they went about their regular dispatching duties. The objective was to verify and expand on the results obtained in the previous three phases.

2. Methods

The preliminary CTA used a hybrid methodology that combined field observations (Mumaw, Roth, Vicente and Burns, 1996; 1997) with structured interview techniques (Militello, Hutton, Pliske, Knight, and Klein, 1997; Potter, Roth, Woods and Elm, 1998).

The preliminary CTA was conducted in four sequential phases:

Phase 1 - Field Observations at a Dispatch Center (Dispatch Center 1): General Orientation;
Phase 2 - Structured Interviews of Expert Dispatchers and Related Personnel: Probing for Details;
Phase 3 - Field Observations at a Second Dispatch Center (Dispatch Center 2): Exploring Generality of the Results; and
Phase 4 - Second Round of Field Observations at (Dispatch Center 1): Verifying and Extending Results.

Each phase built on the results of the prior phases.

Dispatch Center 1 was an Amtrak Dispatch Center in Boston, Massachusetts. It primarily handled passenger trains.

Dispatch Center 2 was a Conrail Dispatch Center in Pittsburgh, Pennsylvania. It primarily handled freight operations.

2.1 Phase 1 - Field Observations at Dispatch Center 1: General Orientation

Two days of field observations were conducted at an Amtrak Dispatch Center in Boston, Massachusetts. The Dispatch Center handled a mixture of local commuter trains, long-distance passenger trains, freight trains, as well as occasional special trains. The bulk of the railroad traffic was long-distance passenger trains. The majority of the track was under signal control, although there were some sections of track that were unsignaled (referred to as dark territory).

A unique aspect of this Dispatch Center was that the track was undergoing extensive maintenance in preparation for the introduction of electrification and high-speed trains.

The objective of the field observations was to gain a broad overview of dispatcher functions, communications between dispatchers and other railroad personnel, and sources of task complexity in preparation for later structured interviews and more focused field observations.

Two observers participated. Each observer sat next to a dispatcher and observed the communications the dispatchers engaged in, and the train routing and track management decisions made. The observer asked the dispatcher questions when invited to do so during low workload periods.

The Dispatch Center was manned by seven dispatchers at a time when each one was controlling a different dispatch territory. Observations were conducted at four of the seven dispatch territory desks. Observations were conducted across two shifts so that a total of eight dispatchers were observed.

The dispatch desks observed encompassed a variety of railroad territory including:

- Train movement in and out of a main railroad terminal;
- Territories that included yard movements;
- Territories that included dark territory (a section of track that is unsignaled);
- Territories that included draw bridges;
- Territories that handled freight; and
- Territories that were undergoing extensive maintenance work in preparation for electrification and so had large portions of track out of service.

Observations included high workload, early morning rush-hour periods; lower workload, mid-day periods; and shift turnovers.

The specific dispatchers that were observed were identified by the Head of Operations. Criteria used in the selection of dispatchers to be observed included having extensive experience and expertise as a dispatcher, ability to articulate a basis for decisions, and willingness to be observed and interviewed.

The objective of observations were to document:

- Dispatchers functions:
  - Routine activities, and
  - Exception handling.
- Information used as input to dispatcher decision-making and safety practices.
- Contributors to cognitive complexity:
  - Inaccurate, incomplete, and/or untimely data delivery;
  - Workload;
  - Communication requirements;
  - Factors that complicate ability to plan/control track use; and
  - Need for "work–arounds."
- Sources of expertise:
  - Strategies that dispatchers have developed to maintain broad situation awareness and "look ahead" (i.e., anticipate and manage track use in the future);
  - Strategies that dispatchers have developed to support planning;
  - Strategies that dispatchers have developed to manage/reduce complexity;
  - Strategies that dispatchers have developed to fill in or make adjustments for inaccurate, incomplete, and/or untimely delivery of data; and
  - Communication strategies that dispatchers have developed to maintain "shared situation awareness" with:
    - Other dispatchers (e.g., dispatchers responsible for adjacent territories);
    - Locomotive engineers;
    - Train conductors;

- MOW personnel; and
- Others.

As part of the field observations, the observers attempted to elicit the dispatcher's perceptions of which of the tasks that when faced with are the most cognitively demanding. An example of a question that addresses this is "Of the tasks you perform, which require difficult cognitive skills? By cognitive skills I mean judgments, assessments, problem solving – thinking skills."

The observers also attempted to elicit and document critical incidents and illustrative cases that reveal:

- The operations and information complications that can arise that increase the cognitive demands on the dispatchers.
- The expert strategies that the dispatchers have developed to deal with those complicating factors.

Questions that the observers asked dispatchers during low workload periods were guided by a checklist of topics that was generated ahead of time. The list of guiding questions is provided in Appendix I. Topics included:

- Questions related to the staffing of the Dispatch Center and the different roles, duties and functions.
- Questions related to decision-making strategies related to the scheduling of trains/allocation of track.
- Questions related to decision-making strategies related to scheduling MOW activities.
- Questions related to complex/unanticipated/unplanned events that can arise and how they are dealt with.
- Questions related to communication requirements.
- Questions related to use of manual and computer-based dispatcher planning aids.
- Questions related to knowledge requirements to perform their jobs.
- Questions related to how they develop and update a situation model.

The list of questions served as a checklist to help the field study observers keep track of which topics had been adequately covered and which topics still needed to be addressed. It provided a framework for guiding and interpreting field observations and served as a basis for formulating questions that were posed to the dispatchers during low workload periods.

2.2 Phase 2 - Structured Interviews of Experienced Dispatchers and Related Personnel: Probing for Details

Phase 2 consisted of structured interviews with experienced dispatchers and related personnel from the railroad Dispatch Center where the first field observations were held.

The purpose of the structured interviews was to explore in more depth dispatcher tasks that the dispatchers identified as (1) cognitively complex, and (2) involving extensive communication with other personnel. The objectives of the interviews were to:

(1) elicit specific cases (illustrative examples) that illustrate the complexities that can arise, and the knowledge and strategies that experienced dispatchers have developed that enabled them to deal with those cases;
(2) obtain a description of types and range of factors that can arise to complicate the task from a cognitive perspective; and
(3) obtain from the dispatcher a description of the types of knowledge and strategies that are used to handle those types of situations.

Based on the results of Phase 1, a set of questions was prepared to guide the more in-depth structured interviews. The structured interview questions that were used are presented in Appendix II.

Three dispatchers were interviewed, one at a time using the structured interview questions. The two observers who conducted the field observations participated in the interviews. Interview topics covered included:

- Complicating factors that made track management and train routing difficult.
- The strategies that they have developed to facilitate performance and maintain the big picture.
- The communication systems and how they used them:
  - The most useful aspects of the systems,
  - The frustrating aspects of the systems, and
  - The benefits and drawbacks of the "party-line" aspect.
- The computer systems in the Dispatch Center and how they use them:
  - The most useful aspects of the systems and
  - The frustrating aspects of the systems.
- Suggestions for improved communication systems and/or computerized support systems.

The interviews lasted approximately 2 hours and were audiotaped.

In addition, an interview was conducted with a commuter locomotive engineer. The objective was to examine the voice radio communication and train routing decision from the perspective of the locomotive engineer to look for convergence and/or divergence of beliefs and opinions. The interview was conducted in the engine cab during a scheduled run. The list of questions used is presented in Appendix II.

An interview also was held with the Superintendent of the Train Dispatch Center where the Phase 1 field observations took place. The objective of this interview was to obtain the management perspective on dispatcher activities, challenges, and opportunities for improvement. The interview lasted 1 hour and was audiotaped. The list of questions used also is presented in Appendix II.

2.3 Phase 3 - Field Observations and Interviews at Dispatch Center 2: Exploring Generality of the Results

Dispatch Center 1, where the initial observations (Phase 1) and interviews (Phase 2) were conducted, was unique in several respects. First, it primarily handled passenger trains. Second, it was undergoing extensive track maintenance work in preparation for electrification and the introduction of high-speed trains.

In order to explore the generality of the findings obtained at the first Dispatch Center, it was decided to conduct field observations at a second Dispatch Center that primarily handled freight operations. The same two observers who participated in Phase 1 and 2, spent a day observing dispatchers at a Conrail Dispatch Center in Pittsburgh, Pennsylvania (Dispatch Center 2).

Dispatch Center 2 dispatched a mix of trains that included passenger trains, scheduled freight trains, and unscheduled freight trains. The majority of the traffic was freight. In particular, the bulk of the traffic involves movement of long-haul coal trains. There were also scheduled intermodal and mail trains. The majority of track was under signal control. A few segments were in dark territory.

Consistent with the objectives of the site visit to this second Dispatch Center, the two observers sat at dispatch desks that primarily handled freight. Each observer sat at one dispatch desk and observed a dispatcher performing his/her duties and asked questions as time permitted. Observations spanned a shift turnover providing the opportunity to observe and interview two dispatchers at each desk, making a total of four dispatchers that were observed.

The same methodology described for Phase 1 was used in Phase 3.

The objective of Phase 3 was to assess to what extent the findings, observed at the Dispatch Center studied in Phases 1 and 2, held for freight operations, and what other additional complications arise with freight operations that need to be considered.

2.4 Phase 4 - Second Round of Field Observations at Dispatch Center 1: Verifying and Extending Results

Two days of additional field observations were conducted at the Dispatch Center studied in Phases 1 and 2. The observations were conducted by one observer and occurred 4 months after the Phase 1 field observations. The methodology employed was the same as described for Phase 1.

The focus of Phase 4 was on (1) collecting additional critical incidents/illustrative examples that further demonstrate the complexities and expert strategies that were described in the interviews, (2) searching for critical incidents/illustrative cases that reveal sources of complexity that were not described in the interviews, and (3) searching for critical incidents/illustrative cases that "on the surface" appear to contradict what was learned in the interviews and exploring the reasons for the apparent discrepancy. It is often difficult for experts to "call to mind" the various complications that can arise in the actual work environment that lead to exceptions to the "rules of thumb" that they have developed and can readily articulate. Searching for discrepancies between what experts "say" and "what they do" is a good strategy for discovering these complicating factors and expert strategies that are otherwise hard for experts to call to mind.

Two dispatchers were observed on the first day, and a third was observed on the second day. Observations were made at two different dispatch desks, one of which had not been observed during Phase 1 observations. As a consequence, a total of five of the seven dispatch desks were observed across Phases 1 and 4.

3. Results

This section reports the findings that were obtained from the four CTA phases. In general, the results from each phase confirmed and extended the results from the previous phase. This was true both with respect to the field observation and interview phases at Dispatcher Center 1 as well as the field observations that were performed at Dispatcher Center 2. While there were differences between the two Dispatch Centers with respect to the specific constraints that dispatchers had to consider in managing track and making routing decisions, and the details of the human-computer interfaces (HCI) available to them, the tasks performed by the dispatchers at the two sites, and the cognitive demands they entailed, appeared to be very similar. Observations at the second Dispatch Center increased confidence in the generality of the findings based on observations at the first Dispatch Center.

The results reported below are primarily based on observations at the first Dispatch Center. Where differences were found between the two Dispatch Centers visited that appeared to affect dispatcher cognitive strategies, they are noted below.

Because the results are primarily derived from observations and interviews at Dispatch Center 1, the operational details reported below generally reflect passenger train operations, and in some cases operational practices that are particular to Dispatch Center 1. While some of the specifics of operation differ between Passenger and Freight Operations, the observations conducted at Dispatch Center 2 suggest that the core conclusions regarding sources of cognitive demands, expert strategies for coping with these demands, and opportunities for aiding should generalize across Dispatch Centers.

3.1 The Railroad Dispatching Environment

3.1.1 Dispatch Center 1

Dispatch Center 1 handles a mixture of long-distance passenger trains, local commuter trains, freight traffic, and special trains. The bulk of the railroad traffic was long-distance passenger trains. The majority of the track was under signal control, although there were some sections of track that were dark territory.

The Dispatch Center has seven dispatchers, each responsible for different adjoining territories. The dispatchers each sit at their own workstation in one large room. Dispatchers can talk directly with those immediately around them (i.e., the dispatcher next to them, in front or back). They can also talk with any dispatcher in the room using an intercom system that they can access through their telephone handset.

In the front of the room there is a large overview display projected on a wall that displays a schematic of the entire set of railroad tracks being controlled from that Dispatch Center. This will be referred to as the wall panel overview. All the dispatchers, as well as supervisory staff, can see the wall panel overview from their own workstation. It provides an overview of track use and train activity throughout the rail system being controlled by that Dispatch Center.

Figure 2 is a picture of Dispatch Center 1. It shows several dispatcher workstations. The large wall panel overview is in the front of the room.

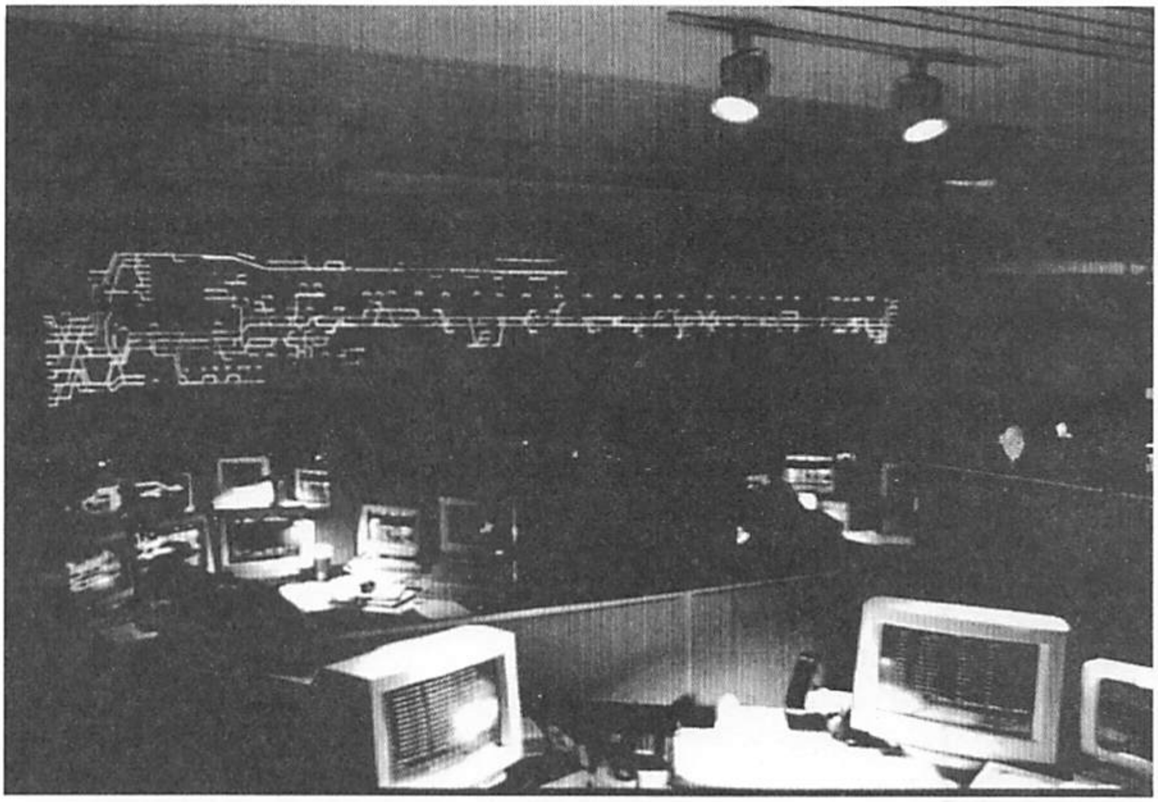

Figure 2. Dispatch Center 1. The Wall Panel Overview Schematic is Projected at the Front of the Room.

On the wall panel overview, a schematic display of the tracks uses color-coding to indicate the status of different segments of track:

- White indicates the segment of track available for routing trains or other uses.
- Green indicates that the segment of track has been cleared for a train routing. When a train reaches that portion of track in the designated direction it will automatically have clear signals to go through.
- Red indicates that a train occupies that segment of track.[2]
- Blue indicates that that section of track is *blocked.* This means that that portion of track has been sectioned off for a specific purpose such as to protect MOW crew or other activities that are not automatically detected by the automatic block signal system.[3] Trains cannot enter a blocked segment of track.

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[2]Alternatively, red may indicate a problem with the sensing system so that it appears as if there is a train on the track. This happened occasionally.

[3]When a section of track is blocked, a blocking device on the CTC machine prevents a controlled signal from being changed to show an indication less restrictive than stop or prevents movement of a controlled switch.

Also displayed on the overview schematic of the track is the current train traffic within the Dispatch Center territory. For each train, the Train ID is displayed above the block of track in which it is located. In addition, an arrow is used to indicate the direction of travel. If the train is late, a numeric value is displayed in red beneath the Train ID number to indicate how many minutes late the train is.[4]

There are four video display terminals (VDT) at each dispatcher's workstation. Three VDTs display train and track use information. These three VDTs are connected to the centralized traffic control system and are used to review train and track use information and to take control actions. The three VDTs have touch screen capability. Two of these VDTs are typically used to present schematic displays of portions of the territory being controlled by that dispatcher. The local schematic displays use a similar graphic representation as the wall panel overview. Dispatchers can take control actions from these displays such as remote setting of track switches, clearing a route for a train, or entering a block on a segment of track to protect MOW workers.

The third VDT is devoted to tabular/textual displays of information related to train status. This third VDT is used to enter information into the computer system such as train identification numbers, and to enter concurrence (as part of a two-step process) when unblocking a portion of track.

Dispatchers' primary means of monitoring activity and communicating with people in the field (i.e., locomotive engineers, MOW personnel, train masters) is via a voice radio system. Dispatchers continuously monitor the road channel that covers communication in their territory and broadcast messages over voice radio. A telephone is available that they occasionally use for one-to-one conversation with people in the field (e.g., MOW foremen, train masters).

The voice communication system is computer controlled and combines radio, telephone, and intercom communication through a single system. The fourth VDT at each dispatcher's desk displays communication information.

There is also a PC at each desk that provides additional information on the status of trains. For example, it provides access to an information reservation and ticket system that is used by ticket agents. It contains schedule information on what time trains are due at stations, actual arrival and departure times (that are manually entered), and late or on-time status.

3.1.2 Dispatch Center 2

Dispatch Center 2 dispatched a mix of trains that included passenger trains, scheduled freight trains, and unscheduled freight trains. The majority of the traffic was freight. In particular, a bulk of the traffic movements were long-haul coal trains. Other traffic included scheduled intermodal and mail trains. The majority of track was under signal control with a few segments of unsignaled track called dark territory.

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[4] The number of minutes the train is late is updated as the train passes each interlocking. The display of minutes late is not always accurate as it depends on whether the scheduled time of arrival has been entered correctly in the computer.

The second Dispatch Center had a slightly different physical layout and computer displays. Nine dispatchers worked in parallel at nine dispatch desks all lined up in a row. Each desk includes four VDTs. One VDT was used for entering and displaying Train IDs, times, and reasons for delays. Two VDTs were used for remotely controlling switches and signals. One of these VDTs is used to enter control commands. The other is used to graphically display the section of track that is being controlled. The fourth VDT is used for the audio communication system.

The most salient difference between the two Dispatch Centers was that there was no large wall-mounted broad overview display available to the dispatchers at Dispatch Center 2. Instead, 66 VDTs were mounted on the wall in front of the dispatch desks. The set of VDTs directly in front of each desk provided a graphic display of the portion of track controlled by that desk. In several cases, the same display appeared on adjacent VDTs. This is because the display included segments of track that were controlled by adjacent dispatchers, and had to be repeated so that both dispatchers could see it clearly. As a consequence, the set of displays on the wall-mounted VDTs did not constitute a continuous representation of the entire track.

As was the case at Dispatch Center 1, the audio communication system at Dispatch Center 2 was computer controlled and combined voice radio, telephone, and intercom communication through a single system. Unlike Dispatch Center 1, the dispatchers at Dispatch Center 2 had headsets that they used to listen to audio communication. This resulted in less noise in the Dispatch Center.

In general, the cognitive demands and dispatcher activities were similar across the two Dispatch Centers. The primary difference observed was that there appeared to be more communication among dispatch desks at Dispatcher Center 2. Dispatchers were observed to get up from their desk and walk over to consult with dispatchers of abutting territories[5] more often at Dispatch Center 2. This may partly be explained by the fact that dispatchers did not have a large wall panel overview depicting the entire Dispatch Center territory to consult for track use and train movements in abutting territories. Also, the Chief Dispatcher supervising the whole center was often observed to walk back and forth behind the row of dispatcher desks at Dispatch Center 2, whereas the Chief Dispatcher at Dispatch Center 1 tended to remain at his desk. It may be that the Chief Dispatcher at Dispatch Center 1 was able to maintain a broad overview of train operations by looking at the large wall panel overview. The Chief Dispatcher at Dispatch Center 2 may have needed to walk back and forth behind the dispatch desks to maintain an equivalent sense of traffic conditions.

These were the primary notable differences in behaviors between the Dispatch Centers. In other respects, the dispatcher activities and strategies observed were very similar across the two Dispatch Centers.

The results reported in the following sections are primarily drawn from observations at Dispatch Center 1. Some of the detailed results may reflect characteristics specific to that Dispatch Center. For example, some results may reflect the fact that Dispatch Center 1 primarily handled

[5] This particularly happened in the case of a dispatcher who controlled a branch line and was sitting several desks away from the dispatcher of the abutting territory.

passenger trains and may not directly transfer to Dispatch Centers that primarily handle freight operations. While the detailed results may not always apply to other Dispatch Centers, the core conclusions regarding sources of cognitive demands, expert strategies for coping with these demands, and opportunities for aiding should generalize across Dispatch Centers.

3.2 Primary Activities of Railroad Dispatchers

Dispatchers have the primary responsibility of controlling track use in the territory assigned to them.

The dispatchers foremost responsibility is to ensure the safety of trains and personnel on the track. This implies ensuring that the operating rules are followed,[6] monitoring train traffic and track use to ensure that no conflict or potentially dangerous situations arise, and alerting locomotive engineers and other personnel of potentially dangerous conditions.

After that, the dispatchers responsibilities are to:

- Route passenger trains efficiently so that the trains meet their schedule. If a regularly scheduled train is more than 5 minutes late, the dispatcher must provide an explanation for the delay.
- Route freight trains and trains from other railroads requesting passage through their territory.
- Route special trains such as privately commissioned cars.
- Schedule safe access time on the track for maintenance and inspection work that needs to be conducted on and around the track (e.g., inspecting the track, fixing a malfunctioning signal or switch).

In most cases, trains operate under centralized traffic control (CTC) or automatic block signal (ABS) control. This means that signal and switch position data, plus block occupancy, is transmitted from the field automatically to the Dispatch Center. As a result, the dispatcher can sense the presence of the train from the Dispatch Center. The train ID will be displayed on the track schematic displays (both the large wall panel overview and the local workstation displays) as the train moves through.[7] In those cases, the dispatcher's primary action is to clear routes ahead of time to allow the train to get automatic signals allowing it to move through the territory. The dispatchers do this using the touch screens on their local workstation VDTs.

Some portions of the track are not under CTC or ABS control. These tracks do not give the dispatchers' any indications when they are occupied and cannot receive dispatcher-directed changes to their signals or switches settings. Track without signals is referred to as *dark territory*. In dark territory, the dispatcher does not get automatic indication of the location of the train, nor does the train get automatic signals allowing the locomotive engineer to move through the territory. In dark territory, the locomotive engineer must call the dispatcher, usually via voice radio when he is about to enter a block of track in a dark territory and request authorization to enter the block. In those cases, the dispatcher must manually block the portion of track in

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[6] This railroad followed the Northeast Operating Rules Advisory Committee (NORAC) Operating Rules.

[7] As is explained later the level of precision about train position is relatively crude.

question (referred to as a block) and issue a Movement Permit Form D (referred to as a Form D) to allow the train to enter that block.[8] The Form D is a written form that is filled out by the dispatcher and read to the locomotive engineer. The locomotive engineer must read back the Form D before it goes into effect. When the locomotive engineer has passed the block, they must call in to indicate that they are through and the Form D is fulfilled.

Some track vehicles (e.g., track cars used for inspection or maintenance) do not activate the signal system even on portions of track that are under CTC or ABS control.[9] Those vehicles are treated similarly to trains in dark territory. They must call in on the radio requesting permission to move into a block. The dispatcher must block the portion of track and then issue a Form D. When the track car has passed the block, the track car operator must call to inform the Dispatcher, who then clears the block.

Inspection and maintenance workers, who will be referred to generically as MOW workers, wishing to work on or around a portion of track, must also call the dispatcher on the radio for occupancy permission. They must indicate the portion of track they need to work on, the nature of the work, and how long the work will take. Requesting time to work on or around the track is referred to as requesting *foul time*. If the dispatcher approves, he will block the portion of track for the workers. If the work involves maintenance of switches or track, then a Form D is issued. If the work involves working around or near the track but not disturbing the track itself, then an *Authority for Equipment to Obstruct Track* form is filled out. In either case, the procedure involves the dispatcher reading the authorization to the worker over the radio, and the worker reading it back for confirmation. As in the previous cases, when the work is completed, the worker calls back to indicate the work has been completed, and the dispatcher clears the block.

In emergencies (e.g., a train derailment, a trespasser is run over) the dispatcher has primary responsibility for coordinating with emergency personnel (e.g., policemen, firemen, ambulances) to handle the situation expeditiously.

In performing their duties, the dispatchers interact with a number of personnel both inside and outside the Dispatch Center.

Other personnel in the Dispatch Center that dispatchers interact with are:

- The *Assistant Chief Dispatcher* who is in charge of daily Dispatch Center operations. This person is commonly referred to as the Chief Dispatcher and sits in the back of the Dispatch Center. The duties include:

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[8] A Form D refers to a specific movement permit form that is issued by railroads operating under NORAC rules. Equivalent forms are issued by railroads operating under other operating rules.

[9] These vehicles do not shunt track circuits.

- Assigning dispatchers work (e.g., if one person is out, assigns someone else to the desk).
- Ensuring that train delays are recorded properly. Dispatchers notify the Chief Dispatcher of any delays to trains, and alert this person to anything that goes wrong that might impact the schedule.
- Locating another train crew for a train if one crew is about to exceed its maximum work time and needs to be relieved.
- Interacting with train crews. For example, in the case of Dispatch Center 1 (which handles primarily passenger trains), before a train leaves a terminal the train conductor will call the Chief Dispatcher to find out whether there are any instructions or restrictions. The conductor at that time informs the Chief Dispatcher of the consist (e.g., the number of cars whether there are any oversized cars, whether there are any dangerous/hazardous materials). The dispatcher issues the clearance and movement authority.

- The *Trouble Desk.* The person in this position is responsible for getting field personnel to fix field problems. This includes any kind of signal trouble, signal system failures, breaks in rail, bridge not working. Typically, a locomotive engineer (or someone else) would call a dispatcher who would then inform the trouble desk. The trouble desk would then call someone out in the field to deal with it.

- The *Clerk* is responsible for entering information into the Centralized Traffic Control System computer. All the information on all the trains, crews, consist, and time on duty is provided to the clerk who inputs it into the computer.

- The *Computer Technician.* The person is this position is responsible for maintaining and troubleshooting computer systems.

The dispatcher also interacts with two additional layers of railroad operations management that are located outside the Dispatch Center proper. The first layer of management is the *Manager of Operations* whose office is immediately outside the Dispatch Center. The second layer of management is the *Superintendent of the Dispatch Center* who heads the entire operation. These two layers of management get involved in weekly and monthly planning and scheduling of railroad operations. On a daily basis, management will be called into dispatching when major incidents and significant schedule delays occur. Table 1 provides an overview of some of the dispatchers' duties.

Table 1. Major Duties and Responsibilities of Dispatchers.

Responsibilities/Duties	Associated Action
Ensure safety of trains and personnel on the track.	• Apply operating rules. • Monitor track use to prevent conflicts or dangerous conditions. • Alert Engineer and other personnel to dangerous conditions.
Ensure that passenger trains meet schedule [under 5 minutes late] and minimize delays when unavoidable.	• Clear routes for trains. • Identify new route when preplanned route is no longer applicable.
Ensure that other rail traffic gets through according to the prioritization scheme.	• Identify route. • Clear route.
Issue and track train movement and track use authorization (Form Ds).	• Block Track for use by MOW/Track Cars/Trains in Dark Territory. • Issue Form Ds.
Control Block Signal on draw-Bridges.	• Switch rail so that if a train runs away it will derail on land and not on water.
Communicate information to locomotive engineer (e.g., temporary speed restrictions).	• Call Engineer on radio.
Communicate track/signal problems to the trouble desk.	• Oral communication.
Communicate schedule delays and conflicts to Chief Dispatcher.	• Oral communication.
In case of emergency coordinate with Emergency Personnel (Police, Fire, etc.).	• Coordinate over voice radio and/or telephone.

Other responsibilities of the Dispatcher are to:

- Inform the trouble desk of track or signal problems so that MOW personnel can be called in to fix it.
- Inform the Chief Dispatcher of situations that might cause train delays or might require action on his part (e.g., if a train crew is about to exceed their time on duty and a fresh crew needs to be located, or if a train engine has a malfunction and a new engine needs to be located).
- Inform locomotive engineers of new information that affects train operation (e.g., temporary speed restrictions).
- Inform locomotive engineer and other personnel of dangerous conditions.

3.3 Dispatcher Train Routing and Track Management Decision-Making

As is explained more fully below, routing regularly scheduled trains that are operating on time is straightforward because there is a preplanned routing strategy. What is more cognitively challenging for the experienced dispatcher is routing trains when there are system variations such as delays, unanticipated trains inserted into the system, or portions of track that become unavailable. In each of these situations, the preplanned route is no longer feasible.

In routing trains, a main concern is to ensure that *meets and passes* occur efficiently. *Meets* are when two trains are coming in opposite directions on the same track. It is important to make sure that trains meet at a location where one train can be placed out of the way (e.g., at a station, on a second track, or at a siding[10]) while the other goes through. *Passes* are when a faster train is coming upon a slower train and needs to pass. Again it is important to make sure that passes occur at a location where the slower train can be moved off the main track or onto a clear adjacent main track to allow the faster train to pass.

In the case of regularly scheduled trains, efficient locations for meets and passes are predefined. A *timetable* for scheduled trains is published from which the dispatchers can derive the location of meets and passes. When trains are delayed, however, or track becomes unavailable, the original location of the meets and passes may become obsolete. In those cases, the dispatcher needs to dynamically identify new candidate locations for meets and passes based on estimates of the current delays and how long it will take the trains to arrive at different locations.

A second source of challenge is balancing the multiple demands placed on track use. If scheduled trains were the only demands placed on track use, they could be straightforwardly accommodated. Cognitive difficulty arises when the dispatcher needs to find windows of opportunity to satisfy unanticipated demands on track use (e.g., MOW work, track cars, special trains, and freight trains). Again, these decisions depend on the ability of the dispatcher to predict how long it will take a train to go from one point to another and arrive at a given location.

Table 2 provides a sample of the types of decisions dispatchers face daily and the factors that enter into those decisions.

[10] A siding is an auxiliary track off the main line, which is used to perform a variety of different functions, such as to allow the meeting or passing of trains, to set off cars, or to change crews.

Table 2. Sample of Types of Decisions Dispatchers Daily Face and the Factors that Influence Decisions

Decision	Sample Situations Where it Arises	Sample Factors Entering into Decision

How to route a train (i.e., which track to place it on, and whether/where to have it cross-over to a different track)?	• Unscheduled trains.[11]
	• Situations where the track normally used is unavailable.
	• Situations where delays have made the prior route infeasible.
		• Speed restrictions on track.
		• Potential track crossovers and associated speed restrictions.
		• Whether there are slower trains in front.
		• What other trains will be needing the track in the near future:
		  • Whether a faster train will be coming through next.
		  • Whether a train is coming through in the other direction.
		• Where anticipated meets will be.
		• Whether there is a platform on that track for the stations at which it needs to stop.
		• Whether a train is late and needs to make up time.
		• What track at a station a train normally comes into:
		  • If a train cannot go on its usual track, then the dispatcher will try to move it to a track very far away to minimize the potential for passengers boarding the wrong train.
		• Train consist (makeup of a train, including locomotives and cars):
		  • Some trains are too long for some tracks.
		  • Some trains are too high to clear overheads (e.g., double-decker trains).
		• What track would be most convenient for the dispatcher in the adjoining territory.

Where to have meets/passes?	• Situations where one or more of the trains is delayed making the preplanned meet/pass points obsolete. • Situations where some track is unavailable, requiring two trains to pass/meet that would otherwise not need to. • Unscheduled trains.	• Requires estimating how long it will take each train to reach a given location. • Requires determining which train to have to wait for the other.

[11] In this report, the phrase "unscheduled train" refers to any train not designated by timetable schedule. This is a broad category that includes both one-time events (e.g., a private train requesting permission to pass through the territory), as well as trains that pass through a territory on a recurring basis (e.g., a freight train that routinely passes through the territory), but where the exact timing of the request to enter the territory cannot be anticipated by the train dispatcher. For the purposes of this report, the primary feature of an unscheduled train is that the dispatcher gets limited advance notice as to when to expect the train to arrive and therefore has limited opportunity to preplan a route for the train.

Table 2. Sample of Types of Decisions Dispatchers Daily Face and the Factors that Influence Decisions (cont.)

Decision	Sample Situations Where it Arises	Sample Factors Entering into Decision

How long will it take a train [or other track vehicle] to get from point A to point B? Approximately how long will a train take to get to point A?	Estimating delays.
	Establishing meets/passes.
	Determining the time window available to allow another train or a MOW activity to occupy track.
		• Maximum speed of train.
		• Speed restrictions on track (both permanent and temporary speed restrictions).
		• Other factors that can affect the speed of a train:
		  • Weather.
		  • Locomotive engineer.
		  • Direction given by Dispatcher.[12]
		Behavior of passengers (e.g., older passengers may take longer to board; if there is a track change, it will create a delay because it will take passengers longer to get to the new platform).

Which train to let through first?	Situations where delays causes a backlog of trains.
	Unscheduled trains.
		• Pre-specified train prioritization:
		  • Passenger trains have priority over freight trains.
		  • Scheduled trains have priority over unscheduled trains.
		  • Fast trains should go ahead of slow trains.
		• How late the train is.
		• Whether the train can make up the time – *"whether there is any rubber."*
		• If a train crew is nearing the 12-hour duty limit, another train may need to be delayed to get the first train through faster.
		• Train prioritization can change with context:
		  • A track car needs to inspect track every 72 hours; if the limit is being approached, then the track car could have priority over a freight train.
		  • With electrification, the dispatcher may hold back the track car and freight train in favor of maintenance work.

[12] For example, in one case, a dispatcher called an engineer to indicate that there had been a change of plan for the location of the next meet (because the other train was delayed). The dispatcher told the engineer to maintain a higher speed in order to arrive at the next meet at around the same time the late train was to arrive.

Table 2. Sample of Types of Decisions Dispatchers Daily Face and the Factors that Influence Decisions (cont.)

Decision	Sample Situations Where it Arises	Sample Factors Entering into Decision
How to help a train make-up time?		• If you can clear a large stretch of track, then it will give a locomotive engineer a better signal when the locomotive engineer reaches the start of the stretch. • If you can put the train on a track authorized for a higher speed. • Crossovers (of track) are slower than going straight. If you want a train to make time, give it a straight track.
Whether to give permission to MOW personnel to work on track?	• MOW foreman (or other crafts personnel) calls in requesting foul time on the track.	• Are there any trains occupying that block now (has the train already passed where the MOW work is to be done)? • How long will the work take? • Are there any trains likely to be coming through during the time the MOW wants to do the work? • If a train comes earlier than expected and the track is needed, how long will it take the MOW workers to clear the track?

Whether there is enough time to give away the track, or allow another train through?	• Scheduled train is delayed, creating a time "window" where:
	  • Maintenance work could be conducted on the track.
	  • A track car could inspect track.
	  • Another train could go through.
		• Estimated time available (i.e., requires projecting impact of delay on train arrival time).
		• Estimated time needed.

3.4 Sources of Input in Making Dispatching Decisions

Dispatchers have a variety of information sources to draw upon in making train routing and track management decisions. These sources include:

- The Centralized Traffic Control System Displays (both the wall panel overview and the workstation VDT displays).
- The PC at their workstation.
- Paper documents.
- Informal notes.
- Personnel in the Dispatch Center.
- Personnel outside the Dispatch Center via voice radio/telephone system.
- Dispatcher's past experience.

A sample of the types of information sources that dispatchers use in making dispatch decisions is provided in this section. The sources listed are not intended to be exhaustive. They include the major sources that dispatchers use and are representative of the kinds of information that dispatchers use.

Examples of the types of information sources, not including other personnel, are listed in Table 3. Examples of personnel providing input to dispatcher decisions are listed in Tables 4 and 5.

Some of the sources provide long-term factual information that remains relatively stable over time. Examples are the operating rules and track charts that provide schematic drawings of the physical track. Track charts show things that are not shown on computer display schematics. Examples include extra sidings that are hand thrown and used by freight trains, grade crossings, and under-grade bridges. Track charts are important for correlating physical landmarks with exact location on the track. They can be particularly useful when communicating with non-railroad personnel (e.g., police, fire) regarding location of points on the track.

Other sources of information contain updates or modifications to the long-term sources and have medium-term application (e.g., applicable over days to weeks). These include documents such as Speed Bulletins that specify temporary speed restrictions.

Lastly, there are sources that provide real-time dynamically updated information. These include the CTC computer displays (both the wall panel overview and the workstation VDT displays) that provide dynamically updated information on the status of tracks, the location of trains and train delays.

The other primary source for real-time dynamic information is other personnel both inside and outside the Dispatch Center. Table 4 provides examples of the types of personnel that dispatchers communicate with inside the Dispatch Center and the types of information that is exchanged. Table 5 provides examples of the types of personnel outside the Dispatch Center. Information from personnel outside the Dispatch Center is communicated by telephone or voice radio.

Table 3. Examples of Information Sources Used by Dispatchers in Making Decisions.

Types of Information Sources	Specific Examples

Centralized Traffic Control System Wall Panel Overview	Graphic Overview of Entire Territory Controlled by the Dispatch Center.
	• Indication of track availability:
	  • Track that is blocked.
	  • Track that is cleared for a train.
	  • Track that is occupied by a train.
	  • Track that is available.
	  • Track that is out of service.
	• Indication of train IDs, what block it is currently in, direction of movement, and minutes late.

Centralized Traffic Control System Workstation Display	• Graphic schematic of track for portions of the territory they control.
	• Record of Train Movement.
	  • The time a train passed particular interlockings.
	  • Information on consist, crew, time on duty.

PC at Workstation	• Information Reservation and Ticketing System. • When train left a station, delays, how many passengers boarded. • Train consist information.

Paper-based Documents	• Operating Rules.
	• Train Schedule/Timetable.
	• Planned Track Outage Schedule.
	• Yard Movement Schedule.
	• Bulletin orders, Special Instructions.
	• Track Charts – drawn to scale charts of the track with more detailed information (e.g., location of stations, platforms, sidings, grade crossings, and streets) than is provided on the computer displays.
	• Lists of important telephone numbers:
	  • Emergency numbers (e.g., police, ambulance).
	  • MOW personnel to contact in case of malfunctioning signals or switches.

Forms prepared by the Dispatcher	• Train Dispatcher's Transfer Record: Form filled at the end of a shift and provided to the next shift dispatcher. • Movement Permit Form D. • Authority for Equipment to Obstruct Track.
Informal Notes Maintained By Dispatcher	• Desk File – Clipboard with formal memos and informal notes providing updates to track status, speed restrictions, and rules of operations. • Cheat Sheet – Personalized sheet with information on train schedule, train meets, and related information tailored to the particular dispatcher's territory.

Table 4. Examples of Personnel in the Dispatch Center that Dispatchers Communicate with and the Types of Information Exchanged.

Personnel	Location	Mode of Communication	Information Dispatcher Passes	Information Passed to Dispatcher
Other Dispatchers	Dispatch Center	Oral	• Train delays. • On what track to expect a train. • Extra trains. • A change in the expected order of trains. • A train coming through with a crew that is approaching their permitted time on shift (12 hours). • To ask whether a dispatcher is ready to receive a train. • To ask on which track the dispatcher would prefer to receive train. • To request that a train be routed on a particular track.	(Same as adjacent column)
Chief Dispatcher	Dispatch Center	Oral	• Train delays; reasons for delay. • Questions of priority – if one of two trains will have to be delayed, which should it be?	Direction on handling difficult or exceptional situations.
Trouble Desk	Dispatch Center	Paper/Oral	• Track, signal, or equipment malfunctions.	
Clerk	Dispatch Center	Paper/Oral	• Train delays; reasons for delay.	
Manager of Operations/ Superintendent of Center		Paper/Oral	• Request for guidance in handling exceptional situations.	• Long-term direction. • Policy.

Table 5. Examples of Personnel Outside the Dispatch Center that Dispatchers Communicate with and the Types of Information Exchanged.

Personnel	Location	Mode of Communication	Information Dispatcher Passes	Information Passed to Dispatcher
Locomotive Engineer/ Train Conductor of Regularly Scheduled Passenger Train	Field	Telephone/Radio	• Speed bulletins. • Any changes in meets. • Explanation for delays. • Inform when another train is about to go ahead of him. • To ask which track they prefer (when there is an option).	• Report track, signal, engine, or equipment malfunctions. • Report obstructions or trespassers on track. • Report consist (particularly if it is longer than usual). • Requests for particular route. • Check whether there are any messages.
Locomotive Engineer of Freight Train	Field	Telephone/Radio		• Destination. • Consist (type of engine, number of cars). • Crew and time on duty.
Locomotive Engineer in Dark Territory	Field	Telephone/Radio	• Issue Form Ds.	• Location. • Request for Form D. • Call in to indicate when clear of a block, so Form D can be canceled.
Track Car/ Non-shunting equipment/ Extra Work Train	Field	Telephone/Radio	• Issue Form Ds.	• Location, destination. • Request for Form D. Call in to indicate when clear of a block, so Form D can be canceled.
Personnel working on or around track (e.g., MOW Foreman, Signal Maintainer, Flagmen)	Field	Telephone/Radio	• Issue Form Ds.	• Requests foul time. • Indicates location of work. • Informs when work is completed and Form D can be canceled.

Table 5. Examples of Personnel Outside the Dispatch Center that Dispatchers Communicate with and the Types of Information Exchanged (cont.)

Personnel	Location	Mode of Communication	Information Dispatcher Passes	Information Passed to Dispatcher
Train Station Director/Train Station Master	Field	Telephone/Radio	• Train delays. • Coordinate on identifying substitute equipment. • Coordinate identifying tracks on which to put trains.	• Train delays leaving station.
Control Tower	Field	Telephone/Radio	• Train delays • On what track to expect a train.	• Train delays. • What track to expect a train on.
Yard Master	Field	Telephone/Radio	• What trains are coming in and on what track. • Coordinate train movements in and out of yard.	• What trains are coming out and on what track.
Emergency Personnel (Fire, Police, Ambulance)	Field	Telephone/Radio	• Location of/ directions to emergency. • Coordinate on emergencies.	• Tracks to be cleared.

3.5 What Makes Railroad Dispatching Difficult?

Routing scheduled trains under signal control is not considered difficult. The tracks to be used, and the meets (the time and place when two trains will meet) are predefined and routing decisions are straightforward.

What makes dispatching difficult is dealing with *unplanned demands* on track use, and the need for changing a *plan* in response to train delays, and track outages.

This requires keeping track of where trains are, whether they will reach destination points (meets, stations) on time or will be delayed, and how long the delays will be. This can be exacerbated in the case of dark territory where trains are not presented on the computer displays.

These are compounded by the fact that:

- Workload is high, and
- Knowledge demands are high.

3.5.1 The Need to Satisfy Multiple Demands Placed on Track Use

One source of complication is the need to satisfy the multiple demands placed on track use that are introduced by unanticipated requests. Dispatchers have the responsibility of meeting these unanticipated requests while still ensuring that scheduled trains are not delayed. Unplanned (and thus unpredictable) demands on track use include:

- Field personnel (e.g., MOW, track cars) requesting time to work on or around the track (inspect and maintain tracks).
- Freight trains that do not have precise schedules.
- Special trains (e.g., test trains, circus trains, trains hired by private parties).

Dispatchers must estimate the time required by these unplanned activities and the time available before the track will be required for a scheduled train. Estimating the size of available time windows to be given away can be difficult. It depends on being able to keep mental track of the scheduled trains (and other activities) that will need to use the track, and being able to project the time at which the trains will arrive at the location in question. Since trains are often delayed, it requires keeping track of where the trains currently are and projecting when the trains will arrive at the location in question, given the current delays and anticipated future delays.

In addition, the demands placed on track use are often greater than can be satisfied at a given point in time, requiring the dispatcher to prioritize and perform triage (determine which activities/trains will be delayed). Dispatchers often have to deny requests by field personnel. Generally, this means that the work needs to be postponed. This imposes an additional cognitive demand on the dispatchers to add the request for time to their mental "queue" and look for a window of opportunity when the work can be performed.

3.5.2 The Need to Dynamically Re-compute Train Routes and Meets

A second source of complexity is that trains are often delayed and/or tracks are taken out of service, making the preplanned routes and meets obsolete and necessitating dynamic re-computation of feasible train routes and meets.

The kinds of decisions that arise due to track outages and/or train delays and factors that need to be considered in making those decisions are outlined in Table 2. Decisions include:

- How to route a train (i.e., which track to place it on, and whether/where to have it cross-over to a different track)?
- Where to have meets/passes?
- Which train to let through first?
- How to help a train make up time?

All these decisions require keeping track of whether trains are on time or delayed and estimating how long it will take a train to get from one point to another.

Keeping track of whether a train is on time or delayed is complex because information on where a train currently is, and whether it is currently running on schedule or is delayed is not available in all cases. Further, in the cases where the information is available, it is not always as accurate or as precise as would be desired.

The CTC system computer displays (both the wall panel overview and the local workstation displays) only provide information on the location and movement of trains within the territory controlled by the Dispatch Center. Dispatchers monitor the voice radio to keep track of the location and delays of trains that have not yet entered the Dispatch Center territory.

Even in the case of trains within the Dispatch Center territory, information on the position of trains is not sufficiently precise. The CTC system displays show that a train is located within a block, but not its precise location. The block can be 5 to 20 miles long. The dispatcher has no way of knowing where the train is within that block, nor even whether it is necessarily moving. As sometimes happens, the train could be stopped for an extended period of time and the dispatcher would not know it.

The CTC system displays do provide information on train delays but that information is only updated as the train passes a control point, and the computed delay depends on the scheduled time that is entered into the computer system. As a result, the delay times displayed are not as timely or accurate as would be needed for precise estimation of delays.

Even if the position of a train was known with great precision, estimating the time it will take the train to go from point A to point B is cognitively difficult because it depends on numerous factors, some well understood and codified, and others less tangible and learned only through experience. For example, the speed at which a train can move across track in part depends on stable characteristics of the track, the physical makeup of the train, and rules of operation that are well documented. The relevant information can be found in paper-based documents such as operating rules and track charts.

Other information depends on more short-term characteristics of the situation such as temporary speed restrictions that are issued on portions of track. This information can be found in updated memoranda and bulletins such as speed bulletins.

Still other information depends on the specifics of the situation. For example, factors such as weather, the temperament of the locomotive engineer, and the types of passengers that board the train (e.g., senior citizens) can all affect the train schedule. The range and influence of these types of factors can only be gained through experience.

As a consequence, dynamically planning routes, estimating arrival times, and scheduling meets and passes require a great deal of knowledge built up from experience. It also requires the ability to integrate the influence of the multiple factors on train movement. Finally, it requires spatial reasoning ability to identify routes, meets, and passes that balance the multiple demands on track use.

3.5.3 High Knowledge Requirements and Memory Load

A fourth source of complexity is that a lot of the information required to make decisions is not directly available from the computer displays and must be recalled from memory or retrieved from paper sources. For example, there are physical constraints that determine under what conditions a train may proceed. The makeup of the train and physical characteristics of the track (i.e., track characteristics that determine allowable speed, height of bridges over track that determines maximum car height, hazardous materials in the rail car that may travel through heavily populated areas) interact to affect the conditions under which a train may move over specified sections of track. The dispatcher must possess knowledge about the track that remains relatively stable and information about the make-up of the train consist which may change constantly as the train proceeds on its journey.

Examples of information that is not available from the computerized displays that influence train movement includes:

- Physical aspects of the track (curves, station platforms, grade crossings, where streets are, where trespassers are likely to go) that are not all represented on the track schematic display. The dispatcher must know they are there.
- Speed limits on different portions of track and crossovers.
- Dark areas that are not covered by the track schematic display. The dispatcher must know their characteristics and keep track "in his head" of what trains/activities are going on in those areas.
- Characteristics of the stations and usual patterns of use.
- Characteristics of the train consist such as number of cars, their height, and whether they are carrying hazardous materials that can influence which track they can go on, which station platforms they can stop at, and at what speed they can travel.
- Characteristics of the locomotive engineer.
- Factors such as weather that influence the condition of the track.

The following scenarios, some of which were observed during the field observations and others of which were described by the dispatchers, illustrate the range of knowledge that dispatchers must bring to bear in planning train routes, estimating delays, and establishing meets and passes. Some of this information is available in paper sources, but others (e.g., impact of behavior of passengers on delays) must be learned from experience.

Case 1: Impact of length of consist

A train had a consist that was longer than usual. The platform the train usually came in on could only hold a locomotive with six cars. This train had two locomotives and six cars. The dispatcher forgot that today the train had an extra locomotive and sent it on the usual track. The train overlapped another block. Hence, this block could not be cleared. Furthermore, two other tracks used this block to exit the station. They were blocked. This resulted in delays to trains on those tracks as well.

Case 2: Impact of weather/physical condition of rail

One day there was a heavy rainstorm. Water started to rise above the rails. The dispatcher was alerted to the problem by a locomotive engineer. The dispatcher had to determine how much water was above the tracks. At some specified number of inches, trains have to slow. At a higher level, they cannot go through at all. Another complication is that water acts as a shunt. As a result, it can make the track appear occupied (red) and the dispatcher cannot clear signals in either direction. The dispatcher had to call a MOW crew to go out to look at the rail. The dispatcher also pulled out the rulebook to determine allowable speed when there is water on the track. The dispatcher consulted with the Assistant Chief Dispatcher because it might have required canceling service. As it happened, it stopped raining so the problem fixed itself.

Case 3: Impact of passenger behavior

A special track car with construction engineers was reviewing the progress of an electrification project. The dispatcher needed to route a passenger train around it. The dispatcher identified a route that he thought would work with minimal delay to the passenger train. The route required that the passenger train stop at a different platform than usual at its next station stop. The passengers were not informed ahead of time of the change in platform. As a result, it took the passengers much longer than usual to board the train resulting in a 9-minute delay for the train, as well as a delay for a second train because it had to wait at a meet for the first train.

This last example illustrates that the behavior of passengers, and factors that may slow passenger boarding, need to be considered in estimating delays. As one dispatcher noted, "If you have icing conditions at a station, it is going to be a long station stop because it is going to be slippery platforms and people are going to have to cross over around the train and it is going to take a while for them driving their baggage. I expect the train to be late out of the station even if it is on time in." [sic]

The temperament of the locomotive engineer can also come into play in estimating train speed. Some locomotive engineers can move quickly and catch up on time and others cannot. As a consequence, it is important for the dispatcher to know the crews and their capabilities.

Also, some trains run on tighter schedules than others. The dispatcher needs to know which trains can make up time if delayed and the portions of track where time can be made up. One example that a dispatcher gave was a case where there was one train coming out of the terminal and another coming toward it. The train coming out was 15 minutes late but had a loose schedule and a long distance over which the dispatcher could make up time. The train coming toward the terminal had a tight schedule and could not make up any delays. As a consequence, the dispatcher let that train come to the terminal first.

All these cases illustrate the need to take into account detailed situation-specific knowledge in estimating delays. In many cases, this information cannot be derived from codified sources (e.g., rulebooks, track charts) and must be built up out of experience.

A final point is that these various factors can interact, further complicating dispatcher decision-making. As an example, one factor to consider in routing a train is the speed limit on different portions of track and crossovers. Interlockings are rated for maximum safe speed. The fastest ones, referred to as fast speed crossovers, are 80 mph. The slowest ones are 15 mph. As a consequence, where you cross over a train has a big impact on it. If the dispatcher wants to maximize train speed then he needs to cross over the train at fast speed crossovers. However, another factor to consider is where the next station stop is. If the train has a station stop shortly after the crossover, then the train will need to slow down. In any case, slowing the train down at an interlocking will not impact the schedule at all.

3.5.4 Mix of Traffic Moving at Different Speeds Can Complicate Computations

Another source of complication in identifying train routes and estimating the time windows available for other work on the track is that the traffic on the rail can go at different speeds.

For example:

- Track equipment operating at 15–20 mph.
- Freight trains and work extras operating at 30 mph.
- Work extras, depending on their consist, can operate at 50 mph.
- Local commuter trains can operate at 80 mph.
- Long-distance passenger trains can operate up to 110 mph.

The wider the mix of traffic speeds, the more complicated the computations become. Currently, there are plans to introduce high-speed trains that can go up to 140–160 mph into the territory. The introduction of high-speed trains will not fundamentally affect the method of computing times. However, the mental computations will become more complex in the sense that trains will be moving at six different speeds, whereas now the trains are moving at five different speeds.

As these new trains are introduced, the time windows between scheduled trains will become shorter, reducing the size of the time windows available for other track use (e.g., freight, track inspection, and maintenance work). This will complicate the track management task further. As one dispatcher explained:

> "It is your extra trains that are going to become a problem. I've got a freight that wants to go from one point to another and it normally takes 25 minutes if he doesn't have any stops along the way. I have to decide whether I have 25 minutes to give him. Or is this liner going to be on his rear end and getting delayed before he gets there. Our windows are going to close for these extra moves. Twenty-five minutes is going to be too much with high-speed trains. So, windows will close for the extra moves. Depending on how frequent the schedules are too. It may force more of the freight trains into night operation."

3.5.5 High Workload/Heavy Attention and Communication Demands

Another source of complexity is heavy attention and communication demands. At any given time, the dispatcher may need to monitor multiple activities in different parts of his territory at a time. In one case, a dispatcher was coordinating two meets in parallel at different parts of his territory and had to simultaneously keep track of two track cars, one of which was in a dark area. The fact that the total set of things to keep track of is not always displayed can exacerbate the problem and increase the likelihood that something is forgotten. Factors that contribute to relevant activities not being visible on the computer displays include:

- Activity in dark territory.
- Inability to put up a dispatcher's entire territory on the two available VDTs.
- Some of the activities that need to be taken into account involve things that have not yet entered the territory controlled by the Dispatch Center.

Traffic over voice radio places particularly high attention demands. One dispatcher estimated 178 communications in one 8-hour shift (i.e., more than one every 3 minutes).

Communications include the need to:

- Answer requests for and issue train movement and track use authorization to locomotive engineers, MOW staff, etc.
- Inform locomotive engineers whether there are any updates to speed bulletins or other messages.
- Find out the status of trains – where they are, why they are delayed.
- Exchange information regarding rail conditions (e.g., broken rail, malfunctioning signals, obstacles on the track, trespassers).
- Coordinate with trainmasters and yard masters.
- Coordinate with emergency response personnel (e.g., police, fire, and ambulance) in accident situations.

Dispatchers indicated that before automatic signal control systems, there were block operators that manually controlled signals and interlockings. One of the benefits of having block operators was that they fielded radio calls, thus reducing the attention demands on dispatchers. When the job of the block operator was eliminated, the dispatcher had to handle all the voice radio requests.

As one dispatcher put it:

> "When I first qualified seven years ago I had nine block operators working for me. People who needed something first called the block operator that controlled the territory where he was. So, the block operator screened a tremendous number of calls. Now all those calls come to my desk – whether it be voice radio or telephone. Since the block operators have been eliminated, all of the calls have been channeled to the dispatcher's desk, which has made routing trains almost like extra work at times. Frequently you have to tell people, "no." Frequently you have to put off a telephone call, and let the

guy on the radio keep calling, because if you don't stop and route the train it is going to be stopped there waiting for you, and of course on-time performance is a company priority."

Typically, while the dispatcher is attending to one request, other calls will come in on voice radio. Of necessity, these calls get delayed in being answered. Dispatchers indicated that some people call repeatedly thinking that the dispatcher is ignoring them when, in fact, the dispatcher is aware of them but attending to someone or something else. This situation is mutually frustrating for both the dispatchers and the individuals trying to contact the dispatcher.

"The problem is I can have three different people all calling at the same time on different radio transmitters. If I'm answering one, the other two can't tell that I am on the line on the radio (because they are not within range of that transmitter), so they will keep calling and calling thinking I'm ignoring him."

The multiple simultaneous requests for attention are one of the drawbacks of having multiple simultaneous communications channels available (e.g., multiple radio channels, telephones). A similar finding was observed by Vanderhorst (1990).

The problem of high attention demand is further exacerbated by the fact that there is too much traffic on voice radio channels. It is widely recognized that voice radio is subject to frequency congestion (Vanderhorst, 1990; Ditmeyer and Smith, 1993). Much of the communication on the radio channel that dispatchers are supposed to monitor (i.e., the road channel) is not relevant to the dispatcher. The road channel is supposed to be reserved for communication between the dispatcher, the train master and the engineer, and people who have to talk to the dispatcher. However, the road channel is routinely used for other types of communication. This includes train crews communicating among themselves, MOW crews communicating with each other, and passenger service-related messages. This imposes additional cognitive burden on the dispatchers since they must listen to enough of these messages to determine that they are not relevant to them. In addition, because of the heavy traffic on voice radio channels, often there will be noise and interference on the channels making it difficult to understand what is being said.

Other sources of workload include the paperwork associated with issuing, revising, and canceling Form Ds. In any given day, a dispatcher can issue many Form Ds that have to be tracked and cancelled when completed. At the end of the shift, the dispatcher is supposed to let the next dispatcher know of any active Form Ds. The actual process of verbally reading a Form D over voice radio, waiting for the receiver to repeat it back for confirmation, and filling out the paperwork is a time-consuming process.

There is substantial workload associated with computer interface management. These tasks involve entering data into the computer and manipulating the interface of the CTC system. Specific interface management tasks include:

- Entering/changing train IDs. One dispatcher mentioned that if an error is made in entering a train ID, it could have repercussions all the way down the line across territories. Another dispatcher indicated that he wished that the page for entering train IDs contained only the list of trains in his territory. Now it contains all trains in the Dispatch Center territory. As a result, he has to scroll through four or more pages to find the ID for the train in which he is interested. Further, IDs build up (temporary IDs are automatically assigned by the centralized traffic control system) by either the entry of actual trains on the track or by problems in track circuit. In addition, train IDs are regularly "lost" by the computer system requiring the dispatcher to re-enter the ID.

- Unblocking a portion of track on the CTC system computer is a time-consuming two-step process. The dispatch must first enter the request to unblock the portion of track on a graphic display and then go to a second screen on another VDT to confirm the request. This requirement is not only time consuming but it uses up valuable space on the VDT. The reason for the two-step process is that the CTC system was originally designed assuming a different dispatcher organizational structure. The CTC system was designed with the assumption that there would be one person taking control actions and a second person providing approval.

- Acknowledging uninformative alarms adds an additional interface management task. The CTC system computer regularly generates alarms that alert the dispatcher to conditions that are perfectly normal and that the dispatcher is aware of already. Nevertheless, the dispatcher must acknowledge the alarm to clear it off the computer screen. In one case, a dispatcher had 120 alarms that covered 8-1/2 pages on his alarm summary screen. As a result, dispatchers have to periodically acknowledge large numbers of alarms in order to clear them.

3.5.6 Summary

Factors that contribute to the difficulty of the dispatcher's job include:

- Demands on track use are high and the margin for flexibility can be low. Trains need to be within 5 minutes of schedule and there are limited routing options available.
- Predicting when a train will arrive or the length of delay can be difficult because it requires keeping track of the progress of multiple trains, some outside the area controlled by the Dispatch Center, and requires knowledge and consideration of multiple factors that can influence train speed.
- Workload, attention, and memory demands are high.
- Attention demands associated with monitoring voice radio channels and responding to voice radio requests are particularly high.

3.6 Expert Strategies to Meet Task Demands

Dispatchers have developed a number of strategies that enable trains to pass through territories more efficiently, and satisfy the multiple demands that are placed on track use. Experienced dispatchers have developed strategies that allow them to anticipate requirements for changes to schedules and planned meets early to have time to take compensatory action. They monitor the wall panel overview, consult with other dispatchers, and "listen for" information on the radio that will allow them to track progress of train movement and get early indication of the need for re-planning.

Some of the strategies used by dispatchers to cope with task demands are described in the following paragraph. Not every dispatcher uses every strategy. The strategies are described to illustrate the types of skills required for the job of dispatcher. These need to be considered in the design of training as well as new displays and decision aids. Awareness of dispatcher strategies is important for designers of new aiding technologies from two perspectives. First, the strategies may signal problems in the dispatching environment that dispatchers are compensating for, and may suggest ideas for new aids that eliminate the need for compensatory strategies. Second, in introducing technologies, designers need to be careful not to inadvertently create conditions that disrupt the ability of dispatchers to utilize effective strategies.

3.6.1 Off-Loading Memory Requirements

There is a great deal of detailed factual information that dispatchers need to make dispatch decisions. This information can be found in the Operating Rules Manual, the train schedules, and various memos and bulletins that update and/or temporarily modify this information.

It is not easy to memorize all of this information. At the same time, quickly locating relevant information from these sources can be difficult. Dispatchers have developed techniques to extract and organize key pieces of information in a more readily accessible form.

One example is what dispatchers refer to as the "Cheat Sheet" or "Dope Sheet." Cheat sheets are sheets that are prepared by each dispatcher that contain key information relevant to his/her own territory. Much of this information is extracted directly from the train time schedule, but is organized in a manner that is more directly useful to the dispatcher. These sheets tend to be highly individualized in their content and format. As an example, one dispatcher's "cheat sheet" contained lists of:

- Interlockings and train stations specific to the dispatcher's territory and when the trains are scheduled to arrive.
- Streets with crossing gates and corresponding milepost.
- Track sidings and the corresponding milepost.
- Hotbox detectors and the corresponding milepost.
- List of communications and signals personnel and their corresponding communications and signals number.

Having ready access to these types of information is important for rapid response to unexpected situations (e.g., a signal malfunction, an accident). The content of the cheat sheets provide clues to the kinds of information that dispatchers need in making dispatch decisions, and suggest that that information is not currently provided in a usable and quickly accessible form.

Another resource that dispatchers have developed to keep track of key information in a readily accessible form is the Desk File or Desk Book. The Desk File is a clipboard with sheets of paper attached. These sheets include formal memos issued, speed bulletins, track outage update forms as well as informal notes generated by the dispatchers themselves. The sheets are ordered with the most recent ones on top and the oldest ones on the bottom. This provides the dispatchers with a convenient way of keeping track of dynamic changes and updates to the status of the track and the rules of operation.

Examples of the types of information kept in a Desk File include:

- Supplemental bulletin orders in effect.
- Temporary speed restrictions in effect.
- Timetable changes.
- Notification of extra train moves.
- Out-of-service notices (e.g., "Switch locking disabled to allow equipment access... track foreman has been notified").
- Interoffice Memoranda from management clarifying policy and rules of operation (e.g., "when adverse weather conditions such as snow affect operations do not let freight trains or work trains out until you know in advance that crossovers and switches are working properly").
- Memos from the Rules Department clarifying interpretation of rules.
- Telephone number updates.
- Handwritten notes from dispatchers alerting to problems/providing tips (e.g., "You can prevent losing Eastbound IDs at a specific location [when bridge opens] by separating train in the ID table...works for track 1 too").

Dispatchers typically review the Desk File at the start of their shift to bring themselves up to speed on the current state of the territory and operation.

3.6.2 Anticipating and Planning Ahead

One of the key hallmarks of experienced dispatchers is that they have developed strategies that allow them to anticipate train movements and demands on track use and plan moves early.

Developing a "Game Plan" to Handle Scheduled Train Meets

Dispatchers work out the location of meets and passes for scheduled trains based on the train timetables and place it on their "cheat sheets." These sheets specify things like what track a train will be routed on (e.g., some tracks hold more cars than others do; certain stations can only be reached from some tracks). The dispatcher usually memorizes his own sheet, but if a new person comes in, it is also useful for them to use.

Generally, these "game plans" are shared and coordinated among the dispatchers (dispatchers on different shifts, on different days, as well as dispatchers on abutting territories). For example, it is desirable that the routing of trains on tracks be the same every day even though there might be different dispatchers on duty on different days. This requires coordination among the dispatchers. Currently, coordination of planned routes is now done in an informal, ad hoc way, using personal time.

Maintaining the Big Picture - Monitoring Activity Beyond Your Own Territory

Dispatchers monitor train activity beyond their own territory. They keep track of where trains that will be entering their territory are and how late they are. As one dispatcher put it: "I need to keep an eye on what's coming at me. How late things are. Things could be coming at me out of order. If things are coming out of the 'expected order' it will require significant planning." Sources of information dispatchers rely on to keep track of train location and delays include:

- The wall panel overview for trains within the territory of control of the Dispatch Center.
- Other dispatchers.
- The PC to access Information Reservation and Ticket System to keep track of trains that have not yet entered the territory controlled by the Dispatch Center.[13]
- Voice radio communication to keep track of trains beyond the Dispatch Center territory where this is possible.[14]

Monitoring beyond their own territory not only helps dispatchers anticipate when trains will reach their own territory, it also allows them to work cooperatively and help each other.

As one dispatcher put it: "You watch the train in the other territory. I've worked almost every desk, and I know almost all the moves in every desk, like a lot of guys do. So, if you see somebody has something wrong, you might say 'Hey this guy comes first.' I might catch somebody else and they might catch me. You say 'Oh yeah, jeez that's right!' Often times somebody might clear a signal ahead of time, not realizing that the westbound is going to come first. It is fairly common. It is not a problem, everyone helps each other out. You are always watching. It is the nature of the job."

Thinking Ahead/Cooperative Planning to Facilitate Train Movement Across Territories

Dispatchers have developed cooperative strategies to provide each other with look ahead and facilitate routing beyond their own territory. They provide each other with status updates to support anticipation, they consult with each other when there are alternative routing options that may differentially impact the abutting dispatcher's territory, and they try to accommodate each other. Dispatchers will:

- Inform the adjoining dispatcher what track he is sending a train on (or will ask which track he wants it on) so that the dispatcher knows which track to expect a train on and therefore what signals must be changed (e.g., when going from two tracks to one track).

- Alert abutting territory dispatchers that there will be a change in the order in which trains will come into their territory (which may trigger re-planning of routes and meets); or in cases where there is a choice, will ask the dispatcher of the abutting territory which one

[13] This applies to Dispatch Center 1 which primarily dealt with passenger trains.

[14] This applies to Dispatch Center 1 where the radio bases were strong enough to pick up voice communication beyond the Dispatch Center territory. It may not apply to Dispatch Centers that primarily handle freight, where the territories are generally larger.

he wants first. If one train will need to turn around right away, the dispatcher will want that train first. An inexperienced person might not know to give a choice.

- Work with adjacent dispatchers on moves to maximize efficiency. As an example, if a dispatcher needs a train on a particular track, and there is a high-speed crossover on an adjacent dispatcher's territory that would allow the switch to be made most efficiently, then the dispatcher will check whether the adjacent dispatcher can have the train cross over while still in his territory.

Taking Advantage of the Voice Radio "Party Line" Feature to Anticipate and Plan Ahead

Dispatchers have developed strategies to extract information from voice radio communication and/or actively seek information to allow them to anticipate delays and plan ahead. They actively monitor how the trains that are headed their way are running.

Dispatchers routinely "listen for" information on the radio channel that is not directly addressed to them but provides important clues to potential delays, problems, or a need for assistance. As one dispatcher put it, "after a while you kind of fine tune your ear to pick up certain key things." Examples include:

- *Identifying when a train has left a station*: The train conductor will generally tell the engineer "OK out of New London," by comparing the time to the scheduled departure, you can compute the delay.

Identifying equipment problems: By overhearing the conversation between a locomotive engineer and the mechanical department, the dispatcher gets early notice of malfunctioning locomotives that will need to be repaired or replaced. In one recent case, there was a train with 500 or 600 people on it and a malfunctioning locomotive. The dispatcher had overheard the engineer call the mechanical department. This allowed the dispatcher to begin thinking about his options early. In this case, he decided to hold another train back in order to minimize the delay of the train with the malfunctioning locomotive.

- *Listening for/heading off potential interactions and conflicts:* Dispatchers at Center 1 could and did listen for commitments made by others that could impact activity in their territory. Dispatch Center 1 had radio bases strong enough for dispatchers to hear conversations beyond their own territory. This may not be typical of other dispatch operations. The ability to listen ahead allowed dispatchers to recognize and resolve potential conflicts early. In one case, a dispatcher overheard a request made by a train to a tower to come out of the yard. In his words "I know when someone is talking to South Bay tower; I know that sure enough South Bay is going to talk to me and I'm going to have to do something about it. So it is anticipation: getting ready ahead of time. Who can go when? Do I want to let him go now? Can the terminal dispatcher handle him now?" He checked with the terminal dispatcher, who was unable to take the train. He then called the tower to ask them to delay the train – all without ever having explicitly been asked.

Listening for mistakes. An experienced dispatcher will pick up key information that may signal a misunderstanding, confusion, or error. A case in point is a situation where an MOW person is working on the wrong track. It is easy for an MOW person, especially an inexperienced one, to become disoriented and work on track for which permission was not given. In one case, a dispatcher overheard a flagman talking to his crew say "OK to come out of the lot at Endels." Endels was across the other side of live track. It was not the track the MOW flagman had requested to be blocked off and protected. The dispatcher immediately put signals to stop and called the MOW person to alert him.

Consider What Can Go Wrong and Plan for Contingencies

Another hallmark of experienced dispatchers is that they think about possible ways things can go wrong and plan for contingencies.

For example, in one case a dispatcher was asked by a foreman for permission to work on a long portion of track. The dispatcher gave approval. He commented at the time that one of the considerations in his decision to give approval was that there were sidings available he could quickly move the foreman to, if it turned out that the track was needed. In the dispatcher's words: " You always leave yourself an out. Don't back yourself into a corner. A big part of staying alive on this job (surviving on the job) is to keep yourself out of trouble by staying out of corners."

A second example that illustrates how dispatchers consider ways things can go wrong and plan for contingencies is a case of a freight train that requested to go through a dispatch territory to get to a yard. In determining whether to let it through, the dispatcher said that he considered: "Do I have time to get the freight into the yard? If I can't get him into the yard, can I get the trains around him? In other words *what if* he has trouble with the switch which happens frequently at this yard... *it's a probability thing*, about once in every five times it fails and they get stuck there. How big is he? Is he going to hang all over the crossover and foul the adjacent track which is going to shut my interlocking all together?" These factors entered into his decision of when to allow the freight train to go and on what track to route it.

3.6.3 Being Proactive

Not only have dispatchers learned to plan ahead, but they have also learned to be proactive, taking advantage of windows of opportunity to meet track demand.

Strategies to Take Advantage of Windows of Opportunity

Dispatchers will act proactively to take advantage of windows of opportunity that are open. For example, a dispatcher may get a request for some track and time (or foul time) from an MOW worker, but cannot give it because a train is scheduled to come through. It was observed if the train becomes delayed, the dispatcher may recognize this as a window of opportunity to satisfy the needs of the MOW worker. The dispatcher may call back the MOW worker and offer some track and time.

In one case, as a second example, a passenger train was delayed (held up in the adjacent territory). The dispatcher used the opportunity to tell a freight train that he could proceed, given that the window of opportunity was open.

Proactive Strategies that Increase Communication Efficiency

Dispatchers and locomotive engineers also act cooperatively and proactively to increase communication efficiency between them, and facilitate train movement. As an example, locomotive engineers are required to check with the dispatcher for messages before leaving a train station. If a dispatcher has the time, he will call the locomotive engineer before he reaches the station to let him know that there are no messages, and that he can leave the station whenever he is ready. This will allow the locomotive engineer to start the trip back in the other direction more quickly.

3.6.4 Leveling Workload

Dispatchers work under externally paced, high attention, demand conditions. Dispatchers have developed strategies to shift workload when possible from high demand periods to lower workload periods. They have also developed skills to perform multiple tasks in parallel.

Shifting Work to Lower Workload Periods

Dispatchers have learned to begin paperwork and bookkeeping duties during low workload period to avoid introducing workload bottlenecks later. Examples include:

- *Pre-naming a train* (i.e., entering it into the computer) before it enters the system to save time later. (Note - if there is a change in the expected order trains are inserted, this will create more work rather than less). At Dispatch Center 1, the dispatcher entered the train schedule number rather than the locomotive number. This is possible because their operations consist primarily of scheduled trains. This pre-naming of the train allows the dispatcher to make better use of their time. It would not apply to other Dispatch Centers that enter trains into the computer system by the Locomotive Number.

- *Beginning to work on documentation requirements in advance.* In cases where someone requests a stretch of track to be blocked and the dispatcher determines that authority cannot be provided at that point in time, but can be provided once certain conditions are met (e.g., a train gets through), the dispatcher will sometimes begin to prepare the forms required for granting the authorities. The dispatcher can begin the process and ask the individual making the request (e.g., a locomotive engineer or MOW worker) to do the same, leaving blank the time the authorization is to go into effect. Later when the conditions for the authorization have been met, the dispatcher can call the person back to complete the process of issuing authorization. This saves time, and serves to level the workload since much of the work involved in granting the authority is done at a time when the workload is not too heavy.

Other related strategies to cope with high workload include:

- Giving MOW foremen as much track as possible all at once rather than in stages to minimize the number of interactions with the dispatcher;
- Giving authorization for track use "until further notice" rather than for a fixed length of time, so that if the MOW needs more time than anticipated and the time is available (e.g., there is no train that needs the track), the MOW can use the extra time without requiring additional paperwork.

Performing Multiple Activities in Parallel

Another skill dispatchers have developed to cope with high workload is that they have learned to perform multiple activities in parallel. In particular, they will often take control actions at the VDT (e.g., placing a block) while they are talking over voice radio or telephone (e.g., giving movement authorization). They will also write a Form D while they are issuing the Form D over voice radio or telephone.

The fact that dispatchers have developed skills to handle multiple tasks in parallel has implications for both training and the design of decision aids.

With respect to the design of decision aids, as new modes of information transmission such as data link are considered, it is important to remain sensitive to the impact of the proposed change in the mode of communication on the relative distribution of workload in the visual versus auditory channels. Right now, dispatchers can listen to the radio (auditory channel) while they are taking action on the VDT screen (visual channel). When considering a shift in communication mode from the audio to visual channel, it is important to consider how the communication task will be integrated with other on-going tasks that involve the visual channel.

With respect to training, the ability to handle multiple tasks in parallel is a skill that requires a lot of practice to develop. It requires each of the individual tasks to become sufficiently automated that multiple tasks can be performed simultaneously. The process of building up these skills was expressed best by one of the dispatchers: "You are listening to the channels on the monitor, talking to someone else on the telephone, and routing a train at the same time. It takes a lot of practice. You have to achieve a certain level of proficiency at each of the tasks individually to be able to think about putting them all together. After a certain amount of time, you do it automatically."

3.7 Suggested Improvements Provided by Dispatchers

This section describes some of the suggestions that dispatchers made for ways to facilitate dispatching. Some suggestions involved application of advanced technologies and development of improved displays. Some of the suggestions were for improvements to training. Finally, some of the suggestions were for changes in work practice. Generally, the suggestions accorded well with the conclusions drawn from the field observations and interviews conducted as part of the project.

3.7.1 Enhanced Information Displays

Some of the suggestions of dispatchers involved improving the information provided in the computer system displays.

Actual Position/More Precise Indication of Train Position

One of the suggestions that was repeatedly mentioned was to provide more precise information on train position. Currently, the exact position of a train in a block and progress of a train within a block is not known with any precision. A train can be anywhere within a 5-mile stretch of track or even stopped and the display looks the same (the stretch of track is color coded to indicate occupied). More precise information on train location would be useful in:

- Estimating delays and projecting how long it will take a train to reach a destination.
- Making decisions regarding giving foul time (or track and time) to MOW workers. For example, if an MOW worker requests permission to work on a block of track in which there is a train, there is currently no way for the dispatcher to know if the train has already gone by the location in question. If the dispatcher could know train position with more precision, then he would know whether the train has passed the location in question and could make the track available for other uses.
- Responding more quickly and efficiently to emergencies. As one dispatcher put it "If you have a five-mile block with one or two grade crossings in the block and get a report that there has been a grade crossing broken, or there is someone on it, it is useful to know whether the train has passed it or not. If you could click a button on the computer and find out exactly where the train is and whether it has passed that crossing it would be very useful. If you are told that there is someone lying down on milepost 171, you want to know if the train has already gone by. You're trying to call that train, but if you could quickly look up in the computer and find out that train has gone by, then you don't have to panic. You are diverting all your energies to find out where this train is but the computer could generate that down to a few feet."

The FRA is currently investigating ways to obtain more precise information on train position by using Global Positioning System (GPS) technology to establish train position and data link technology to transmit information on train position to the dispatchers. Tests of Positive Train Control technology a decade ago demonstrated how GPS combined with data link technology could be used to provide real-time information on train position and speed (Vanderhorst, 1990).

Indication of Train Speed Judged Less Useful

Systems that provide precise train location information also would be able to provide more precise information on train speed.

There was mixed reaction with respect to whether providing instantaneous indication of train speed would be useful.

Some dispatchers believe it would be useful to help them determine whether trains were maintaining track speed, and to be better able to anticipate whether a train would reach the station on time. It also would be useful to detect cases where trains were going too fast for track conditions. A recent instance was noted where a train was going too fast and crashed. The dispatchers were criticized for not catching the excessive speed, but given the installed technology it is not possible to determine train speed.

Other dispatchers felt that instantaneous train speed would not be particularly helpful in estimating delays and projecting the time to reach a destination. They were also concerned that locomotive engineers might not like to have their speed so closely monitored.

3.7.2 Shift Paper Resources to Electronic Media for More Rapid Access

There were several suggestions made by dispatchers to transfer documents that are currently in paper form to computer form for more ready access.

Specific documents mentioned were:

- *Track charts.* The ability to visualize the physical characteristics of the track and the surrounding landmarks was considered very important. It was viewed as particularly important in trying to understand what locations MOW workers were referring to when they called in asking for foul time. As one dispatcher put it: "It is a safety issue to know exactly where the guy is. 'This is where I am standing. This is the track that I am going to be obstructing.' Visualizing the interlockings is key. These are the worst things that are drawn out of scale on the computer displays. If I had a visual of the interlocking, I could know what someone meant when they said 50 feet from the interlocking or 100 feet west of the switch. Right now I can't tell where that is. On the display, it is nowhere near drawn to scale so relying on memory." Dispatcher comments made clear that it would be useful to have a drawn-to-scale reference map.

- *Street maps overlaid on track charts.* Track charts show streets over the railroad or under, but not side streets. It is important to know the side streets to guide emergency vehicles. As one example, there was a person that was struck on the rail. The dispatcher knew where the train was stopped on the rail, but didn't know the location of side streets to direct the firemen. A dispatcher indicated that he kept his personal copy of a city map to help him understand his territory. Dispatcher comments indicated that they would find it useful to be able to quickly call up information on streets surrounding the track on the computer.

- *Desk File.* The desk file contains track status updates, speed bulletins, and rule modifications that impact train routing decisions. Dispatcher comments indicated that it would be useful to be able to access that information more readily.

- *Electronic rule book.* Similarly, the operating rules contain hundreds of very detailed rules that govern train movement and track use. It is difficult to retrieve a particular rule when needed. One dispatcher pointed out that it would be nice if you could go to the computer and type in a term and retrieve the applicable rule. (e.g., flat spots on wheels).

3.7.3 Planning/Scheduling Aid

One suggestion that was mentioned by the Superintendent of the Dispatch Center was a planning/scheduling aid that could be used to support planning unscheduled maintenance activities and train reroutes. This tool would benefit Dispatch Center personnel who have to deal with requests for extended track outages for unscheduled maintenance work in the medium-term future (e.g., 8 to 12 hours in the future).[15]

Dispatch Center personnel often get requests for extended track outages for unscheduled maintenance work. For example, they may get a call from an MOW foreman asking "We need to do some work tonight. How much time can we get?" The Dispatch Center l personnel have to look at train schedules, string lines, and track outages to determine the answer manually. It would be helpful if there were traffic planning software where a person could enter the proposed track outages (e.g., take block of track "X" out of service) and have the computer show the consequences (e.g., show the impact on train routing and train delays). The FRA is currently supporting research to develop string line displays that addresses this function.

A planning tool also might be useful in helping Dispatch Center staff deal with complex train routing problems that go across the territories of multiple dispatchers. For example, there are situations, such as trains that are chronically late, that require an adjustment to the routing assumed by the preplanned schedule based on the train timetables. Developing an optimal solution for dealing with the chronically late train might best be handled by considering the train routing across dispatch territories rather than by having each dispatcher deal with the problem from the perspective of their own territory.

In addition, a planning tool would be a useful aid as a "what if" tool. For example, managers are responsible for reviewing situations where trains had significant delays. Each morning, a meeting is held to review train delays. A tool that would help the staff ask "what if" questions such as "what would have happened if train A had been held back to let train B go?" would be a useful aid. It also would be useful as a tool to anticipate potential problems in the coming day's schedule. It could help Dispatch Center staff answer questions such as "What potential problems could arise today and how might we deal with them?"

There is currently ongoing research to develop planning and scheduling aids for real-time railroad dispatching. For example, Burlington Northern Railroad pioneered work on real-time planning systems (Ditmeyer and Smith, 1993). The real-time planning system included two online control systems, the Tactical Traffic Planner (TTP) and the Strategic Traffic Planner (STP). The primary function of the TTP is to generate an efficient plan for meeting and passing trains on a dispatcher's territory. The TTP takes detailed train movement information provided

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[15] At Dispatch Center 1, planning for unscheduled maintenance work is often done by the Superintendent of the Dispatch Center.

via digital data link and compares it with desired train performance. If there are significant deviations from the plan, the TTP will re-plan, adjusting meet and pass locations to recover undesired lateness. The STP operates at a more "strategic" control level, establishing train priorities and schedule targets. The STP will change train priorities and schedules to accommodate external constraints such as delayed connections from other railroads. The STP makes cost-minimizing decisions on a real-time basis, on whether and how, train priorities and schedules should be adjusted.

Research on planning and scheduling aids for railroad dispatching is continuing. For example, the FRA is currently funding research to develop graphic visualization aids to support dispatchers in routing trains and planning and scheduling MOW work.

3.7.4 Message Board

Another suggestion was to provide a dynamic computer-driven message board display as an extension to the wall panel overview. This would be used to post operational information updates such as upcoming track outages and special train moves. This would provide a shared-view display that could be seen by all the dispatchers, providing a common frame of reference on upcoming events that impact train routing. It also could be used to alert dispatchers to different levels of urgency in the Dispatch Center (e.g., if there is an emergency at one of the dispatcher territories). Announcing an emergency level would alert the dispatchers in the other territories to the problem and the need to minimize distractions and support the dispatcher with the emergency.

3.7.5 Shifting Some Voice Radio Communication to Other Media

There was general agreement that there was too much congestion over the voice radio and that some of the types of communication that dispatchers currently conduct over the radio do not lend themselves well to that media. Dispatchers provided several suggestions for shifting some types of communication to other media.

Gracefully Transitioning from Voice Radio to More Private Communication Channels

One of the main advantages of the voice radio is its broadcast capability. Calling someone on the voice radio is an efficient way to quickly get a message to someone when you are not sure of their location or have ready access to their telephone number. However, it is not a good medium for conducting extended conversations that involve detailed descriptions of locations or instructions. As one dispatcher put it:

> "Detailed instruction is tough on the radio. In one case, there was a flagman calling in looking for foul time on one of the tracks, and the dispatcher wasn't sure whether the flagman knew where the location was that they were agreeing on. The dispatcher would have preferred to ask the flagman to switch to a phone line so that he would find out exactly where the flagman was. On the radio you say 10 feet west of this, of that, you get cut, the flagman is not really sure of himself, the dispatcher is not sure what is going on. On a phone, you can narrow it down right away and you are not under the

same kind of time pressure. On the radio, you are reluctant to tie up the communication line. Also, it is embarrassing for an MOW to say on the radio that they aren't sure where a location is or aren't sure of instruction. On the phone one can discuss things at length without the same time pressure or interference as on the radio."

One solution that several dispatchers suggested was to develop a technology that would allow a dispatcher to gracefully shift from the voice radio channel to another media (e.g., a portable cell phone or a private communication line via data link). The idea would be to take advantage of the ability of the voice radio to catch someone's attention and then shift to another media such as a cell phone or a private communication data link to conduct more extensive communication. Some MOW workers are using personal cell phones to interact with dispatchers. The FRA is currently investigating the use of interactive text and voice systems using "leading edge" wireless technology. This concept, coupled with the suggestion provided by other dispatchers to provide visualization aids to aid dispatchers and MOW personnel in discussing the exact location where maintenance work is to be conducted, would seem like an idea that would have positive safety implications.

Transmitting Messages and Authorization Forms Using Data Link

Several dispatchers mentioned that Form D authorization forms that are currently read by the dispatcher and then verbally acknowledged by the recipient over the voice radio could be more effectively transmitted digitally. Digital transmission includes technologies such as fax as well as computer technologies that would display the information on a computer screen.

The advantage of digital transmission is that the recipient would have the information visually displayed. This would reduce the amount of time required on the voice radio to issue a Form D, and would reduce potential errors resulting from oral communication over the radio.

Messages and authorization forms that dispatchers mentioned would be most useful to shift to digital media include:

- Movement authorization forms (e.g., Form Ds), and
- Blanket orders such as speed summary bulletins and supplementary bulletins.

With respect to messages that are blanket orders to be disseminated to all locomotive engineers, the shift to digital media would have the added advantage that the dispatcher could transmit the information to everyone at once. Currently, the dispatcher has to relay the information by telephone or voice radio to the trains one-by-one. With a digital system, the dispatcher could transmit the message to everyone with one keystroke. The locomotive engineers could then read the information when their workload permitted it and then send a digital acknowledgment. This system would contribute significantly to a reduced workload on the part of dispatchers and would allow the locomotive engineers to more effectively manage their workload by allowing them to shift reading of messages to lower workload periods.

Dispatchers mentioned that some of these concepts are already being implemented or are in the planning stages. For example, dispatchers indicated that some railroads already use a fax to transmit messages and Form Ds.

Providing a "Call Back" Capability

Dispatchers stated that they are overloaded so they often are unable to respond immediately when a locomotive engineer or MOW person calls. This frustrates the caller and sometimes results in a vicious cycle of the person calling and calling (to get the dispatcher's attention) and the dispatcher becoming more and more frustrated with the caller because it is adding to the background noise on the radio, and does not allow the dispatcher to concentrate on the current task (e.g., speaking to someone on the telephone). The interviewee suggested that if there were a way to acknowledge receipt of a radio call (without taking the call), and having the computer automatically generate a "call back" list, it might alleviate the problem of callers feeling a need to repeatedly call back.

3.7.6 Work Practice Improvements

Several of the suggestions made by dispatchers for ways to improve dispatching involved suggestions for improvement in work practice.

One suggestion made by a dispatcher is that the process of going from a train timetable to a "game plan" of exactly how the trains will be routed and where the meets and passes will be, should be a more formal process. A team of experienced dispatchers should be allowed to work on an "overall game plan" that would address train movements across territories, shifts, and across days. Right now, the dispatchers are given the schedule and equipment swaps and are expected to work out the details, individually, on their own time. They are not given the time to coordinate with other shifts and abutting territories.

It was also pointed out that dispatchers have information that would be useful to incorporate into the basic schedule. For example, dispatchers know that some trains may be chronically late (e.g., even on its best day, it is 2 or 3 minutes late). Every time there is a schedule change, it would be useful if a couple of the experienced dispatchers were allowed to review it and provide input ahead of time.

The interviewees stressed that dispatchers be given dedicated time to work on these plans. Right now they are asked to do it on their own time, or as time allows as they are performing their dispatching duties, and that is difficult to do.

3.7.7 Training

There was general consensus among the dispatchers interviewed that the current training process for dispatchers had room for improvement.

In the past, train dispatchers tended to come from the ranks of tower block operators.[16] There used to be a minimum of 5 years of block operator experience to become a dispatcher. The tower block operator would get relevant experience because the dispatchers would delegate simple dispatching activities to them.

Now dispatchers are recruited "off the street" or from other railroads. They get approximately 8 weeks of classroom training where they learn basic terminology, facts, and rules of operation. They also get 2 weeks of training on a simulator of the CTC system computer displays where they learn to manipulate displays and take control actions. The bulk of the skills involved in dispatching are expected to be learned from experienced dispatchers in apprenticeship mode. Following the 2 weeks of computer training, they are "posted" with an experienced dispatcher for a period of 6 to 12 weeks. They sit at the desk next to the experienced dispatcher who explains the job to them as time permits. They also are sent on field trips where they have the opportunity to ride on a train where they can speak with the locomotive engineer and learn the territory visually.

Dispatchers expressed concern that given the heavy workload of the job, they were too busy to be able to provide the new dispatcher trainees with the level of explanation and experience that was required for them to learn the job efficiently.

Dispatchers suggested that more use could be made of the simulation facilities to expose the trainees to complex dispatching situations so that the trainees can develop the knowledge and skills required to handle these situations. As one dispatcher put it:

> "I think they need to go into some kind of simulation for quite a long time, not 2 weeks on Centralized Traffic Control System training. That is not the simulation they need. They need real time. They need to get hammered by fake foremen, track cars showing up. Give them realistic situations for 6 months and see if they can deal with it. Real busy situations: computer system failures, hurricanes, washouts, the whole thing. Give them the whole aspect. Don't give them 2 weeks on a fake thing and make it seem like this is what it is all about."

> "You could do it right in the Centralized Traffic Control System simulator. You can create a foreman simulator voice. I think they need the whole aspect of it. I know you have simulation now in the Centralized Traffic Control System simulator where trains pop up, but that is just traffic. That's just punching A to B. That is real simple. I think they need the whole aspect of it."

> "A disabled train, a fatality. What do you do? What happens when someone gets hit by the train? Some day you are going to have to deal with it. Brand new people off the street, they may not know that if you hit somebody on mainline 1, then you better have mainline 3 and mainline 2 protected. They may not know that. It is things like that that are scary and it is not their fault. They just don't have 'the know how'. And if they had 6 months of simulator training and learning the job, some of them may decide its not for

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[16] The term tower block operator is used by Amtrak. In other railroads, dispatchers may have come out of the ranks of agent/telegraphers.

them, and some of them may really come away with a whole new appreciation for the job. I think the real problem is that they don't appreciate what they really are doing. They don't have the real feeling, the understanding of what really is going on out there. It is easy to look up at this board and see it is like a computer game. It is not a game. It is very serious."

The above quote from a dispatcher eloquently lays out the training issue. The current simulator training serves only to familiarize the dispatcher trainees with the mechanics of manipulating the computer interfaces and taking control actions (e.g., how to clear a route, how to input a block). It doesn't provide the dispatcher with experience in making complex routing decisions (What route to clear? What factors to consider in identifying a route?). Those complex decision-making skills are expected to be learned in apprenticeship mode from experienced dispatchers. The difficulty is that the experienced dispatchers are busy and are not always able in real-time to explain the rationale behind their dispatch decisions. Also, in any given 6-week period of actual operation, it is not possible to experience the broad range of situations that dispatchers need to learn about and cope with. A training simulator where dispatcher trainees could be systematically exposed to gradually more complex simulated situations would be a useful complement to the existing training process.

While the details of the training program described above may be specific to Dispatch Center 1, the general issues raised regarding dispatcher training are likely to be broadly applicable across Dispatch Centers. In many cases, classroom and simulator time is used to train the rules and mechanics of train routing. Decision-making skills are learned in apprenticeship mode. More use can be made of simulators to teach cognitive and decision-making skills more efficiently and effectively.

4. Discussion

The results of the CTA reveal that the way dispatching is currently done, is a cognitively demanding task that depends on the ability of dispatchers to monitor train movement beyond their territory in order to anticipate delays. Dispatchers must maintain broad awareness of activities in their territory, balance multiple demands that are placed on track use, and make rapid decisions regarding train routing and track use.

The ability to perform these tasks depends on extensive knowledge and cognitive skills that are built up through experience. Dispatchers have developed a variety of strategies that enable trains to pass through territories safely and efficiently and satisfy the multiple demands placed on track use. These strategies include techniques to off-load memory requirements, and techniques to extract information about train movement and track activity to support anticipation and planning; strategies that allow them to act proactively, taking advantage of windows of opportunity to satisfy the multiple demands that are placed on track use; and strategies to level workload.

Many of these strategies depend on communication and coordination among individuals distributed across time and space. One basis for coordination is the use of voice radio as a communication device that provides for a shared frame of reference. The ability to "listen in" on communications directed at others that have a bearing on achievement of their own goals, and to recognize when information in their possession is of relevance to others and to broadcast it are important contributors to efficient management of track use in today's environment.

The CTA revealed two findings that on the surface appear to be contradictory. On the one hand, the dispatchers interviewed felt that the voice radio channel was congested, resulting in high attention load for the dispatchers. At the same time, the CTA revealed that dispatchers believed they extract valuable information from the "party-line" aspect of voice radio. While these findings appear to suggest opposite conclusions, they can be reconciled. The key is to identify ways to deploy new technologies that off-load voice radio communication while still providing the kinds of information that dispatchers extract from the party-line aspect of voice communication.

As new technologies, such as data link, are introduced, the specific strategies that dispatchers employ to extract information, develop broad situation awareness, maintain a shared frame of reference, and anticipate and plan ahead, may shift. In today's environment, dispatchers rely on party-line radio communication to extract information needed to support situation awareness and planning ahead. Properly deployed data link systems can provide the needed information more directly and effectively.

With the advent of high-speed trains, the cognitive demands and workload will increase further. Understanding the sources of cognitive demands that are imposed on dispatchers and the strategies that dispatchers have developed to cope with these demands can suggest ways to improve performance through training and/or the introduction of new technologies that reduce cognitive complexity so as to increase the safety and efficiency of railroad operations.

The results of this CTA suggest ideas for the application of technologies such as advanced computer displays, decision aids, and data link communication to improve train routing, safety, and efficiency (Ditmeyer and Smith, 1993). They also have potential implications for selection and training of new dispatchers (Reinach, Gertler, and Kuehn, 1998).

In the following paragraphs, the potential implications of the results for development of advanced displays and decision aids, data link technology, and new forms of training are discussed.

Ideas for future research that are suggested by and built upon the findings of this CTA provide a conclusion.

4.1 Implications for Advanced Displays and Decision Aids

Section 3.7 described a number of suggestions for how new information, visualizations, and decision aids could be used to support dispatcher decision making. These suggestions fell into several categories:

- Ways to enhance the ability of dispatchers to track train progress and anticipate train delays.
- Ways to help dispatchers more readily access the detailed information that affect train routing and track use decisions.
- Ways to help dispatchers visualize the physical layout of the track and surrounding geography.
- Planning aids for dynamically identifying train routes and establishing meets and passes.

4.1.1 More Accurate Train Movement and Location Information

With respect to ways to help dispatchers track train progress, there was consensus that more accurate information on train location and train movement would be useful. This would help dispatchers better anticipate train delays, as well as manage track use more efficiently. The value of providing instantaneous indication of train speed is less clear.

One of the findings of the study is that dispatchers track train movement beyond their own territory, and in some cases beyond the territory managed by the Dispatch Center. In creating displays to support dispatchers in tracking train location and movement, it will be important to clearly define the range within which dispatchers need to be able to track trains that will eventually be entering their territory.

4.1.2 Electronic Data Bases

With respect to helping dispatchers access detailed information relevant to train routing and track-use decisions, the results of the CTA revealed that there are many sources that contain information relevant to dispatch decisions. Examples include the operating rules, train timetables, speed bulletins, track outage schedules, policy updates, telephone numbers, and contents of the desk file. This information is currently accessible only in paper form and dispersed in many separate documents. As a result, dispatchers cannot easily refer to these documents in making real-time dispatch decisions and must rely on their memory of the document contents. If these documents were converted to electronic form and cross-indexed in such a way that information relevant to particular dispatch decisions could more readily be accessed, it would better support dispatch decisions.

4.1.3 Visual Representations of Track and Surrounding Environment

With respect to helping dispatchers visualize the physical track and surrounding geography, the CTA results revealed that many dispatch decisions depend on having accurate knowledge of the physical layout of the track and surrounding geography. Dispatchers stressed that this is critical to maintaining the safety of personnel working on the track as well as enabling dispatchers to effectively coordinate response in emergencies. Currently, the computer displays of the track are schematic representations that are neither sufficiently accurate nor detailed enough to support dispatchers in visualizing the physical track. It would be useful to add displays to the computer system that would provide more accurate visualizations of the track and surrounding streets. For example, it would be useful to have a drawn-to-scale view of the track with accurate positioning of the interlocks that could be electronically called up on the CRT. It also would be useful to have a street map overlay on the track display that would show accurate representation of side streets (e.g., to guide emergency personnel). One other useful idea would be to provide a similar display capability to personnel working on the track (e.g., on a handheld computer) to ensure a common understanding of the specific portion of track that the dispatcher is giving permission to foul.

Another useful category of decision aids to pursue is planning aids for dynamically identifying train routes and establishing meets and passes. As the CTA revealed, unplanned events pose the greatest challenge to dispatchers. Dispatchers could clearly benefit from decision aids that would help them manage unplanned events more effectively.

4.1.4 Planning and Scheduling Aids

As discussed in Section 3.7.3, there is need for planning and scheduling aids for dispatchers. One clear application is support for the longer range planning (i.e., several hours to several days in advance) that is performed by Dispatch Center personnel who routinely are faced with requests for track outage or scheduling of special trains.

A real-time planning aid for dispatchers would also be beneficial. Development of a real-time planning aid is likely to be more technically challenging. As the CTA results revealed, predicting train delays involves a great deal of knowledge of the specific situation (e.g., time of day, weather, state of the track, behavior of passengers, characteristics of engineer) that may not be fully taken into account by a planning tool (Roth, Malin and Schreckenghost, 1997). Research on planning and scheduling aids for railroad dispatching is progressing in promising directions. For example, the FRA is currently funding research to develop graphic visualization aids to support dispatchers in routing trains, and planning and scheduling MOW work.

4.2 Implications for Data Link Technology

4.2.1 Provides Method for Off-Loading Voice Radio Communications

There was a clear consensus that voice radio channels are now overloaded and that there is a need to off-load some of the communication onto other media. Further, there was clear indication that the voice radio is not well suited to some of the types of communication that are now conducted on it. For example, long dialogues intended to convey detailed information, such as exact location, are best conducted on a more private channel. These long dialogues would benefit from the availability of visual graphics to provide a common frame of reference and avoid misunderstandings. Similarly, reading aloud and then repeating back complicated Form Ds ties up the dispatcher and the person receiving the Form D longer than necessary and is error prone.

Data link technology provides a vehicle for taking information that is now passed over the voice radio and transferring it over data link instead (Ditmeyer and Smith, 1993). This means that information that is currently communicated orally over the radio could be presented visually on a computer display instead. This has clear benefits for certain types of information such as movement authorization forms, and blanket orders such as speed summary bulletins and supplementary bulletins.

This conclusion is consistent with the results reported by Vanderhorst (1990) who compared traditional voice radio communication with corresponding data link versions of the same interactions. Vanderhorst examined all the communications that took place during a 2-hour span at the desk of a dispatcher at an actual Dispatch Center. He analyzed actual records of the sequence of radio and telephone exchanges over the 2-hour period and constructed corresponding (hypothetical) data link versions of the same interactions. From his analysis, he concluded that:

1. Data link reduces the dispatcher's communication load by making train times and locations and other train information continuously available at the dispatcher's workstation and by automating such basic control functions as authority issuance and work assignment.
2. Data link improves a dispatcher's communication efficiency by reducing communication failures, delays, breakdowns, conflicts, and repetitions.
3. Data link increases dispatcher's communication precision by supplying accurate, real-time information and by making it readily available all the time.
4. Data link radically changes the dispatcher's communication focus by reducing or eliminating the types of messages most common with the traditional dispatching media (time and location messages and movement authority transactions), so that planning and problem solving replace information gathering and movement authorization as the dispatcher's primary tasks.

While Vanderhorst (1990) identified cases where data link had clear advantages over voice radio, he concluded that data link should supplement, but not eliminate, voice radio as a communication medium between train or MOW crews and the Dispatch Center.

4.2.2 Mode of Presentation Should Depend on Nature of Communication

As mentioned in the introduction, data link affords a great deal of flexibility with respect to when, to whom, and how messages are presented. With data link communications, messages can be discretely addressed to a single individual or broadcast to multiple recipients. Information can be presented visually (e.g., as text or graphics) or acoustically (e.g., as audio or voice). The communication can involve real-time interaction among the parties (synchronous communication) or it can be sent at one point in time and accessed at a later point in time (asynchronous communication).

Different types of communication have different presentation requirements. These should be considered in assessing what communication to shift off of voice radio and the most appropriate mode of presentation for that type of communication.

Messages that involve detailed instruction and precise location information, such as movement authorization forms are best communicated via a private channel with the information presented visually and can be stored so they are easily reviewed. In contrast, messages that involve alerts to hazards on the track (e.g., obstacles, broken rails, trespassers) are more appropriately communicated on a broadcast channel so as to most efficiently reach the most number of individuals that are potentially affected.

Data link technology could be used in broadcast mode. This was demonstrated by Malsch, Sheridan, and Multer (in press) who examined two different data link systems: a discrete system where messages were directed to a discrete recipient, and a broadcast system. In the broadcast system, dispatchers had the ability to select a group of recipients to whom the message will be sent. While both systems improved efficiency over voice radio communication, the broadcast data link system proved most efficient for transmitting hazard alerts.

4.2.3 Ensure that Cognitive and Collaborative Tasks Supported by Radio Party-Line Feature Continue to be Supported

A final point relates to the benefits associated with the party-line aspect of radio communication. Dispatchers reported that they routinely "listen for" information on the radio channel that is not directly addressed to them but provides important clues to potential delays, problems, or a need for assistance. This finding does not imply that the "party line" aspect of radio communication should be preserved in its present form. Rather, the results should be viewed as an indication of the kinds of information that dispatchers need to be effective. The fact that dispatchers are currently extracting this information by overhearing conversations is symptomatic of the paucity of information provided to dispatchers in today's environment. The information now broadcast as speech can often be better presented in a visual display.

In many cases the information that dispatchers were able to extract by "listening" to communication that was not explicitly directed at them could be more effectively communicated through data link systems that present more precise and timely information on train location and status. Cases in point include situations where dispatchers listen to communication between a train engineer and a conductor to infer when a train had left a station; and situations where dispatchers learn about train engine problems by overhearing a conversation between the locomotive engineer and a mechanic.

The party-line feature of the radio also was used to detect mistakes. For example, dispatchers reported detecting errors by overhearing conversations that revealed that individuals were working on sections of the track where they were not supposed to be. These cases highlight the need to provide displays and communication support that reduce the potential for error and enable dispatchers to readily recognize and correct errors that are made. An example is the use of "shared graphic" displays that allow the MOW worker and the dispatcher to both see at the same time the portion of track for which foul time is being requested/granted. This type of shared graphic display should reduce the potential for misunderstandings and communication errors. Malsch, Sheridan, and Multer (in press) implemented this type of shared graphic displays in their study of data link systems. They concluded that the shared graphic displays were instrumental in improving communication and reducing potential for error.

4.3 Implications for Selection and Training

In the past, dispatchers tended to rise from the ranks of tower block operators or agent/telegraphers. The tower block operator would get relevant experience because the dispatchers would delegate simple dispatching activities to them. Further, since new dispatchers were recruited from the pool of block operators, management already knew a lot about the individuals and their capabilities when they recruited them. Similarly, the individuals applying for dispatch positions were already familiar with the job and so were in a good position to know whether the position would suit them. In those circumstances, formal selection and training procedures were less of an issue.

Currently, there is a growing trend to recruit dispatchers "off the street." They get some classroom training where they learn basic terminology, facts, and rules of operation (Reinach, Gertler, and Kuehn, 1998). They also get some simulator training where they learn to manipulate displays and take control actions. The bulk of the skills involved in dispatching are expected to be learned from experienced dispatchers in apprenticeship mode. Apprenticeship, while an effective approach to training, is not necessarily the most efficient way to build up the knowledge and skills required to make effective dispatch decisions. An apprenticeship approach to training is particularly challenging in environments such as dispatching where the real-time workload demands are high, making it difficult for dispatchers to provide the level of explanation for making decisions that is required to support developing equivalent decision-making skills in trainees.

4.3.1 Develop Objective Selection Tests to Measure Cognitive Skills Needed in Dispatching

Interviews with dispatchers and Dispatch Center management suggested that there might be some value in exploring ways to augment the current dispatcher selection and training process.

The current selection process relies primarily on interviews. Developing some objective tests in combination with interviews may result in an improved selection process. For example, based on the CTA, the dispatcher's task requires visual-spatial reasoning and spatial manipulation.

Dispatchers are required to project train movement in time and space and to visualize where work is to be conducted on track. Questions that require visual projection include:

- When and where will trains meet?
- Which train is likely to pass through first?
- Where on the track is the MOW foreman asking for foul time?
- Can I squeeze an activity in the window available (e.g., a freight train, foul time)?

Developing tests that tap this type of spatial reasoning and correlate well with some aspects of dispatch performance may improve the selection process. More research would be needed to explore the link between spatial reasoning and dispatch performance (if any) and to use the results to develop a predictive test.

4.3.2 Develop Simulator-Based Training of Decision-Making Skills

With respect to training, simulator-based training can augment the apprenticeship training to more rapidly bring new trainees up to a high level of performance (Mumaw, Swatzler, Roth and Thomas, 1994).

The training on a simulator of the CTC system could be expanded to provide more practice on the cognitive and decision-making skills required to handle complex dispatching situations. Currently, dispatchers are given very simple exercises on the CTC system simulator that are intended to teach the trainees the mechanics of how to use the computer system (e.g., how to bring up a display, how to acknowledge an alarm, how to clear a route, how to enter and remove a block). The simulator is not used to teach decision-making skills. More use could be made of the simulation facilities to expose trainees to complex dispatching situations so that the trainees can develop the knowledge and skills required to handle these situations. Examples include cases where there are switch failures, extra trains, trains with long consists, and train derailments.

Section 3.6 described some types of knowledge and decision-making skills that underlie expert dispatch performance. Currently, these types of knowledge and skills are developed from experience. It may be possible to accelerate the learning process through systematic exposure to training scenarios on a simulator that exercise those knowledge and skills (Mumaw, et al., 1994). Examples of skills that need to be developed that might benefit from simulator training include:

- Strategies to support anticipation.
- Strategies to maintain broad awareness.
- Cooperative strategies to maximize route efficiency.
- Strategies for anticipating problems and planning contingencies.
- Strategies for leveling workload.
- Strategies for performing multiple tasks in parallel.

Training could be more focused on building up these specific cognitive skills and expert strategies. The skills could be developed by providing progressive experience and practice in handling complex scenarios that require applying those skills in a simulator environment. Some examples of these cognitive skills and sample scenarios are listed in Table 6.

Table 6. Examples of Cognitive Skills and Sample Scenarios that Could be Used on a Simulator to Exercise Them.

Maintaining the big picture: An inexperienced person is subject to tunnel vision. They focus on an important move and lose track of the other things that are going around them. *Scenario:* There is an important train that is heading east but will not reach the territory for a half-hour. Meanwhile, there is a train heading west that is slowly moving toward the territory and will reach the dispatcher's territory first. Does the dispatcher recognize the need to clear the train going west first, or does the dispatcher focus prematurely on the important eastbound train?
Looking for efficient moves beyond their own territory: Dispatchers need to work with adjacent dispatchers on moves to maximize efficiency. Scenarios can be created to determine whether dispatchers can recognize a way to make a move more efficiently beyond their own territory. *Scenario:* A train needs to get on track 2, but the crossover on the dispatcher's territory is slow. The train is delayed and needs to make up time. There is a faster crossover on the abutting dispatcher's territory. Does the dispatcher recognize this and ask the abutting dispatcher to cross him over onto track 2 before sending the train into the dispatcher's territory?
Considering what could go wrong and prepare contingencies: A characteristic of an experienced dispatcher is the ability to look ahead, anticipate potential problems, and plan contingencies. *Scenario*: A freight train with an extra long consist requests a move through an interlocking into a yard. There are two scheduled trains coming to the same interlocking: one from the east and one from the west. In deciding whether to let the freight train through does the trainee consider whether time is available to get the train to the freight yard before one of the passenger trains comes through? Does the trainee consider the possibility of the freight train getting stuck at the interlocking and fouling the adjacent track (because of its length it hangs over the crossover blocking movement in both directions) in selecting which of two tracks on which to route the train?

4.4 Future Research Directions

The CTA that was conducted was intended to provide an overview of the dispatching environment, the cognitive demands placed on dispatchers, and the strategies that experienced dispatchers have developed in response to those demands.

The primary goals of the study were (1) to demonstrate the methods and value of CTA analyses, and (2) to produce initial results to help guide future, more focused, research and development programs aimed at improving information displays, communication and computer-assisted dispatching systems. Its primary contribution has been to highlight the major sources of cognitive demands of dispatchers and the opportunities for more effective support, for communication, developing effective information displays, or training.

Future research, targeting particular aiding approaches (e.g., cognitive skill training programs, dispatcher selection processes, data link technologies, new visualizations, advanced decision aids), will require more narrowly focused, in-depth CTAs. For example, the detailed organizing principles by which dispatchers store and retrieve information today, and how they will need to do it in the future are still not known. If a model of how dispatchers make decisions that guide how they allocate track or determine train movements were developed, more information would be needed. This type of model would be useful in developing cognitive skill training programs, as well as real-time planning aids.

There are a number of future research directions suggested by the present study. One direction is to pursue one of the aiding approaches that was identified in the study. One promising candidate is to develop simulator-based training programs for training the types of cognitive skills that expert dispatchers displayed. Other good candidates are to develop one or more of the decision-aiding concepts described in Sections 3.7, 4.1, and 4.2.

Other fruitful directions include broadening the range of Dispatch Centers that are studied. This study focused on one Dispatch Center that primarily handled passenger trains. A second Dispatch Center that handled freight trains was visited, but the focus was on reassuring the authors that the basic findings observed at Dispatch Center 1 held for Dispatch Center 2. Additional studies that explicitly explore the cognitive demands that arise in handling freight operations that do not arise with passenger train operations would be valuable.

Studies of Dispatch Centers that primarily handle freight operations exist and were reviewed as part of this CTA study (e.g., Vanderhorst, 1990). Much valuable information on the communications aspect of dispatching was gained from the Vanderhorst (1990) report. The Vanderhorst report focused on the comparison of conventional voice-based communication systems and proposed data link systems. The cognitive task analysis documented here built on the Vanderhorst report but covered a broader set of considerations. It examined the information requirements of dispatchers, their strategies for managing train operations, implications for training, and the factors to be considered in the development of computer-assisted support systems that might be embodied in future train control systems.

It also would be valuable to contrast operations at Dispatch Centers that vary in their level of technological support to understand the impact of alternative technologies on dispatcher cognitive demands and performance. One of the striking differences in dispatcher performance observed between Dispatch Center 1 and Dispatch Center 2 related to the fact that Dispatch Center 1 had a large wall panel overview of the dispatch territory whereas Dispatch Center 2 did not. This may have strongly influenced the communication patterns among dispatchers at the two Dispatch Centers. This unexpected finding highlights the importance of interface technology on Dispatcher cognitive performance. Studies that explicitly explore the impact of display technology on dispatcher cognitive performance may yield valuable insights for guiding future interface development.

Another unexpected finding of the study that is worth further exploration is that there turns out to be a good deal of ad hoc coordination among the dispatchers within a Dispatch Center in making train routing decisions. Local decisions made by one dispatcher have global impact. More efficient and safe operation could occur with better coordination among the dispatchers. Understanding more fully the effect of team decision making on performance in a Dispatch Center and how it could be improved would be a productive research endeavor.

A final research area to pursue is job design. With new technology support, system designers and the railroad industry can think about the reallocation of functions between the operator and the equipment. How might the nature of what the dispatchers do change? For example, one of the unforeseen side effects of automating the physical job of the Block Operator is that many of the monitoring and decision making responsibilities of the Block Operator fell to the Dispatcher. As the railroads adopt new technologies, the impact of the changes on the cognitive as well as the physical workload of workers must be anticipated.

Appendix I: Questions that Guided Field Observations

The following set of questions served as a checklist that was used during the field observations at the two Dispatch Centers. The list of questions provided a framework for guiding and interpreting field observations. It helped the field study observers keep track of which topics had been adequately covered and which topics still needed to be addressed. The list also served as a basis for formulating questions that were posed to the dispatchers during low workload periods.

Questions related to the staffing of the Dispatch Center and the different roles, duties and functions:

- Dispatchers,
- Chief Dispatcher, and
- Trouble Desk.

Among the questions asked will include those about the size of the dispatch territory, how the size is determined, whether the size changes (e.g., on the day shift versus a night shift) and on what basis.

Questions related to decision-making strategies related to the scheduling of trains/allocation of track:

- Issuing train movement and protective authority (including issuing authority in "dark territory").
- Use of train schedules.
- Estimating travel times between two locations for a variety of train make-ups over a variety of road, track, and operating conditions.
- Estimating/planning train meets and passes.
- Priority allocation strategies.

Questions related to decision-making strategies related to scheduling Maintenance-of-Way activities:

- How they determine when and where maintenance can be done.

Questions related to complex/unanticipated/unplanned events that can arise and how they are dealt with:

- If a new train is inserted in the network.
- Unexpected maintenance job.
- Unplanned delay.
- Competing demands for track use.
- Equipment malfunctions (e.g., responding to wayside defect detectors).
- Train malfunctions (e.g., train has a broken drawbar).
- Accidents/emergencies.

Questions related to communication requirements:

- Who they communicate with (other dispatchers, chief dispatcher, MOW personnel, locomotive engineers, train conductors, yard master).
- Modes of communication (by telephone, in person, by writing, by two-way radio, through changes in signals).
- Form and content of communication (including purpose of the communication):
  - Formal communication processes (the process by which warrants are issued).
  - Informal communication practices.
  - Routine communication:
    - Time and location messages.
    - Movement authority transactions.
    - Maintenance-of-way activity.

- Who is the communication explicitly intended for and who else can monitor the communication (i.e., party line – broadcast mode):
  - Is there a benefit to the party-line?
    - What do the dispatchers "listen for" and what do they get out of the radio channel?
    - The locomotive engineer?
    - The train conductor?
    - The maintenance-of-way personnel?
- Factors that make communication difficult:
  - Frequency congestion/saturation of the communications channel.
- Errors/confusions that can arise/have arisen.

Questions related to use of manual and computer-based dispatcher planning aids:

- What they are, how they are used.
  - The large wall panel display overview schematic of the railroad's territories.
  - Workstation displays the dispatcher's own territory.
  - Planning sheet (where all schedules are issued and updated online).
  - Schedules and timetables.
  - Train movement authorities.
  - Track bulletins, dispatcher bulletins, special instructions, and other updates that are used to dispatch trains and protect track users.
  - Maintenance plans.

Questions related to knowledge requirements to perform their jobs:

- Physical characteristics of the territory for which the dispatchers are responsible.
- Certified on a particular portion of the network they work on.
- Do they stay with a territory or get assigned different territories at different times?
- Do they stay with a particular shift or do they change?
- What do they do to get "up to speed" when given a new territory to deal with?

- Do they memorize the schedule of traveling trains and their destinations?
- Do they know the physical characteristics of their territory (e.g., size of sidings, location of switches and geographical aspects of territory – where there are curves)?
- Do they know the locomotive engineers? Do they meet with them (e.g., at the start of a shift? Once a week, etc.)?
- Do they know the maintenance-of-way personnel? Do they meet with them on a regular basis?

Questions related to how they develop and update a situation model:

- What information do they seek/get during a shift turnover? At the start of a shift?
- Documents and other sources of information that they check prior to assuming responsibility for a desk.
- What information do they record/provide at the end of a shift/during a shift turnover?
- What activities do they engage in when they are assigned a "new" shift or a "new" territory?
- Do they "pay attention" to activity in other sectors? How? How does it influence their own decisions (i.e., anticipate future impact on them of activities in adjoining territory? Consider impact of their decisions on other dispatchers)?
- How they plan beyond the limits of their own territory and keep adjoining dispatchers apprised of information needed on approaching trains.

Appendix II: Questions Used In Structured Interviews

Interview Questions Used with Railroad Dispatcher

We are interested in understanding how you plan and control track use. What makes the task hard, and what strategies you have developed that allow you to route trains efficiently and meet the multiple demands placed on track use. One area we are particularly interested in is the kinds of communications involved in doing your job (particularly the communications over the voice radio and telephone lines).

We are going to be asking you some questions. Some are intended to get at what makes your job hard and the strategies and skills you've developed to deal with the job demands. We'll be trying to get examples of specific situations that have recently occurred that illustrate your points.

We'll also be asking you for suggestions for things that could be done to make your job easier and increase track management efficiency and safety.

Part 1:

Complicating Factors: We are interested in how you plan and control track use, what makes it hard, and the strategies you have developed for handling hard cases.

- Can you tell me about some of the complications that can arise to make this task hard?
- Can you give me a recent example that illustrates your point?
- In this case, how did you handle the situation?
- How does what you did differ from what a less experienced person might have done in a similar situation?

Big Picture: New people on the job may only see bits and pieces (e.g., consider individual trains at a time). Experts are able to quickly build an understanding of the whole situation – the Big Picture view. This allows the expert to think about how different elements fit together and affect each other; they can look further ahead, anticipate, and head off problems.

Can you give me an example of what is important about the Big Picture for routing trains and managing track use? What are the major elements you have to know and keep track of?

Can you give me a recent case where having the "big picture" helped in efficiently routing trains and meeting the multiple demands placed on track use?

Do you pay attention to activities in other territories? How does it influence your decisions?

Do you plan beyond the limits of your own territory? How do you keep adjoining dispatchers apprised of information they need?

Job Smarts/Improvisation: Experts can see beyond standard operating procedures. They don't cut corners, but they don't waste time and resources either. Experts are comfortable improvising – seeing what will work in a particular situation. They are able to shift directions to take advantage of opportunities.

In your job, are there ways of working smart that you have found especially useful?

Can you think of an example when you have had to improvise to adapt to the demands of a situation?

Impact of Background: New dispatchers don't come in with the experience levels and knowledge of railroad operations that dispatchers have who started out as block operators. Have you observed differences in how they perform their dispatcher functions? If yes, can you describe these differences?

For each probe we will ask the following follow-up questions as appropriate:

- In this situation, how did you decide what to do? What cues and strategies did you rely on?
- What made the situation hard to handle? In what ways would this be difficult for a less experienced person?

Part 2:

1. What would you say is the most challenging/cognitively demanding part of your work? Why?

2. What is the most frustrating part of your work? Why?

3. If you could redesign your job (the way tasks are divided up, the job rules and practices, the computer displays, voice radios and aids available) what things would you change to improve train routing efficiency and/or safety?

4. Lets focus on the communication systems (i.e., the telephone and radio communication system):

- What do you think are the most useful aspects of the system (compared with before)?
- What are the most frustrating aspects of the system?
- What improvements would you want to see?
- The voice radio system has the property that many people can hear a message that you broadcast (i.e., serves as a party line), whereas the telephone system is more private.
  - Is there a benefit to the party-line aspect?
  - What do you as a dispatcher "listen for" and what do you get out of voice radio traffic?
  - Can you give examples of cases where there are advantages of people overhearing a message you broadcast over the voice radio (other than the person to whom it is directly intended)?
  - Can you give examples of types of communication now transmitted over the voice radio that would be better off transmitted over a more private channel (such as a telephone line, a fax, or a computer display)?
  - Can you think of cases where there would be advantages to broadcasting a message to more or different people than is currently possible over the voice radio (e.g., a message that would benefit from being transmitted to individuals across territory boundaries)?
  - Can you think of examples of message traffic that are now conducted over the voice radio or over telephone lines that would be preferable if it were transmitted by other means (e.g., via computer displays, via fax)?
    - How about Form Ds?
    - How about messages that are bulletin updates?
  - Would you rather have voice radio with the benefit of overheard information or telephone that is more private but might mean a delay in when you hear about something?

5. Let's consider the computer system (i.e., VDT displays; large wall panel displays):
   - What do you think are the most useful aspects of the system (compared with before)?
   - What are the most frustrating aspects of the system?
   - What improvements would you want to see?
   - Is there some information that would be useful to have that is not now available on the computer system (i.e., that would improve your decision-making or help you)?
     - How about train speed?
     - How about more precise information on the location of trains?
     - How about more precise information on the location of track cars?
     - How about more detailed information about the terrain (e.g., where crossings are, where curved track is)?
     - How about information that you now have to keep in your head or write down on paper? Are there any external memory aids that would be helpful (e.g., computer equivalents to post-it notes)?

6. Dispatchers often have to work on multiple things at a time (e.g., you might have to keep track of multiple trains at once and consider multiple requests for foul time). Is that a problem for you? Would you like to have some kind of help for that?

7. We understand that electrification is underway and that soon high-speed trains will be introduced. What impact do you think that will have on your job? Do you think it will change the strategies that you use for routing trains and managing track use? Do you have any suggestions for changes in work practice or introduction of new displays or decision aids that would make it easier to handle the new mix of traffic?

Interview Questions Used with Locomotive Engineer

The focus of our project is on how dispatchers do their job. A big part of a dispatcher's job is to communicate and coordinate with locomotive engineers. So we thought we would include locomotive engineers among the people we interviewed to make sure we included their perspective.

1. What are the types of communication that go on between locomotive engineers and dispatchers?

2. Let's start with the routine situations that require communication:
   - Who initiates the call?
   - What information is communicated?

3. Can you give me some recent examples of unanticipated situations that required the dispatcher to contact you? (Ask them to describe the situation: What information was communicated, how was the situation resolved?)

4. Can you give me some recent examples of unanticipated situations that required you to contact the dispatcher? (Ask them to describe the situation.)

5. Do you always contact the dispatcher over the voice radio or do you ever use means (e.g., a cell phone)?

6. Do you ever contact people other than the dispatcher in charge of the territory you are in (e.g., other engineers, MOW staff, dispatchers in other territories)? Describe some recent examples.

7. The voice radio has the property that you can "overhear" conversations intended for others (i.e., the party-line aspect). Is there a benefit to this feature from the point of view of a locomotive engineer? What do you as a locomotive engineer "listen for" and what do you get out of the voice radio traffic?

Interview Questions Used with the Superintendent of the Dispatch Center

1. What do you see as the most challenging/cognitively demanding part of the dispatchers' job?

2. What do you see as opportunities for use of new technologies to improve track management efficiency and safety?
   - Opportunities for data link technologies?
   - Opportunities for new information displays/visualizations (e.g., string diagram)?
   - Opportunities for scheduling aids?

3. Thinking about Dispatcher Center operations more generally, where do you think there is the most opportunity for job changes/introduction of technology for improvement in efficiency? In safety?

4. How do you think new electrification/introduction of high-speed trains will impact the dispatchers' job?
   - Do you see implications for job responsibility (e.g., size of territory; number of dispatchers)?
   - Do you see implications for training?
   - Do you see implications for decision aids?

5. Let's focus on the communication systems (i.e., the telephone and radio communication system):
   - What do you think are the most useful aspects of the system (compared with before)?
   - What are the most frustrating aspects of the system?
   - What improvements would you want to see?
   - The voice radio system has the property that many people can hear a message that you broadcast (i.e., serves as a party line), whereas the telephone system is more private.
     - Is there a benefit to the party-line aspect?
     - Can you give examples of cases where there are advantages of people overhearing a message you broadcast over the voice radio (other than the person to whom it is directly intended)?
     - Can you give examples of types of communication now transmitted over the voice radio that would be better off transmitted over a more private channel (such as a telephone line, a fax, or a computer display)?
     - Can you think of cases where there would be advantages to broadcasting a message to more or different people than is currently possible over the voice radio (e.g., a message that would benefit from being transmitted to individuals across territory boundaries)?
     - Can you think of examples of message traffic that are now conducted over the voice radio or over telephone lines that would be preferable if it were transmitted by other means (e.g., via computer displays, via fax)?
       - How about Form Ds?
       - How about messages that are bulletin updates?

- Would you rather have voice radio with the benefit of overheard information or telephone that is more private but might mean a delay in when you hear about something?

6. Let's consider the computer system (i.e., VDT displays, wall panel displays):

- What do you think are the most useful aspects of the system (compared with before)?
- What are the most frustrating aspects of the system?
- What improvements would you want to see?
- Is there some information that would be useful to have that is not now available on the computer system (i.e., that would improve your decision-making or help you)?
  - How about train speed?
  - How about more precise information on the location of trains?
  - How about more precise information on the location of track cars?
  - How about more detailed information about the terrain (e.g., where crossings are, where curved track is)?
  - How about information that you now have to keep in your head or write down on paper? Are there any external memory aids that would be helpful (e.g., computer equivalents to post-it notes)?

8. New dispatchers don't come in with the experience levels and knowledge of railroad operations that dispatchers who started out as block operators. Have you observed differences in how they perform their dispatcher functions? If yes, can you describe these differences?

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