UNDERSTANDING HOW RAILROAD DISPATCHERS MANAGE AND CONTROL TRAINS: A COGNITIVE TASK ANALYSIS OF A DISTRIBUTED TEAM PLANNING TASK*

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A Cognitive Task Analysis was conducted to examine how experienced railroad dispatchers manage track use. The results reveal the cognitive complexities faced by dispatchers and the cognitive and collaborative strategies developed in response to those demands, including strategies to support anticipation and planning, and proactive strategies to exploit windows of opportunity to satisfy the multiple demands on track use. In many cases these strategies depend on communication and cooperation among individuals distributed across time and space (i.e., multiple dispatchers, locomotive engineers, maintenance of way personnel). The ability to "listen in" on communications directed at others that have a bearing on achievement of your own goals and to recognize when information in your possession is of relevance to others, are important contributors to safe and efficient track use. The results reinforce findings from other domains (e.g., space shuttle mission control, air traffic control) regarding the role of a shared communication channel in supporting anticipation and contingency planning. Implication for the introduction of advanced "data-link" communication technologies, as well as for dispatcher training are discussed.

INTRODUCTION

Railroad dispatching is critical to the safety and efficiency of railroad operations. The railroad dispatcher is responsible for allocating and assigning track use, insuring that trains are routed safely and efficiently, and insuring the safety of personnel working on and around railroad track.

As part of it's 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 Cognitive Task Analysis (CTA) to examine how experienced railroad dispatchers manage and schedule trains in today's environment.

CTA methods have grown out of the need to explicitly identify and take into account the cognitive requirements inherent in performing complex tasks (Schraagen, Chipman & Shalin, in press; Potter, Roth, Woods and Elm, in press). This includes the knowledge, mental processes and decisions that are required to perform a task. CTAs reveal (1) the factors that contribute to cognitive performance difficulty; (2) the knowledge and skills that expert practitioners have developed to cope with task demands; and (3) opportunities to improve individual and team cognitive performance in a domain through new forms of training, user interfaces, or decision-aids.

An important aim of the CTA was to identify (1) cognitive activities that could be supported more effectively through the introduction of "data link" digital communication systems. A second, related aim, was to identify features of the existing environment that contribute to effective performance and therefore should be preserved when deploying these new technologies.

An interesting element of the railroad dispatching environment is that it involves extensive communication and coordination among individuals distributed in time and space. In a typical railroad dispatch center there are multiple dispatchers working in parallel, each responsible for different territories, who must coordinate with each other, and with locomotive engineers, and workers on the track (maintenance of way or MOW workers) in order to manage track usage efficiently and minimize train delays. The fact that railroad dispatching requires communication and coordination among multiple individuals who vary in scope of responsibility, task focus, and access to information makes this an example of a distributed team planning task (Smith, McCoy & Orasanu, 1998). The distributed planning aspect of the railroad dispatching environment is not widely recognized in the industry, and as a result is not explicitly trained nor directly supported. One of the contributions of the CTA was to make more explicit the distributed planning aspect of the dispatcher's job and to reveal the communication and cooperative planning strategies that dispatchers have developed to facilitate safe and efficient train movement and track usage. This paper focuses on those findings. A more

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complete report of the CTA findings can be found in Roth & Malsch (1999).

METHODOLOGY

The CTA used a hybrid methodology that combined field observations at dispatch centers with structured interviews with experienced dispatchers. The CTA was conducted in four phases. Phase 1 involved two days of observations of railroad dispatchers as they went about their job in their actual work environment in a railroad dispatch center that primarily handled passenger trains. Two observers participated. Each observer sat next to a railroad dispatcher and observed the communications he or she engaged in, and the train routing and track management decisions made. The observer asked the dispatcher questions during low workload periods. Questions were guided by a checklist of topics to be covered that was generated ahead of time.

A total of 8 dispatchers were observed across two shifts. Observations included high workload early morning rush-hour periods, lower workload mid-day periods, and shift turnovers.

Phase 2 consisted of structured interviews with experienced railroad 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; strategies that they have developed to facilitate performance and maintain the big picture; Issues in training new dispatchers; and 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. This 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 was to verify and expand on the results obtained in the previous three phases**.** Phases 3 and 4 employed the same methodology as Phase 1. A complete description of the study methodology can be found in Roth & Malsch, 1999.

In general the results from each phase confirmed and extended the results from the previous phase.

OVERVIEW OF CURRENT DISPATCHING ENVIRONMENT

The two dispatch centers we observed were similar in physical layout, and dispatcher duties. For economy of space only Dispatcher Center 1 is described.

The Dispatch Center has 7 dispatchers working in parallel, 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 phone handset.

In the front of the room there is a large wall projected display that provides an overview of track usage and train activity throughout the rail system being controlled by that dispatch center. In addition each dispatcher has several video display terminals at his or her own workstation. Three are devoted to display of train and track usage information. Dispatchers can take control actions from these displays such as remote setting of track switches, clearing a route for a train, or blocking a segment of track to protect MOW workers.

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

WHAT MAKES RAILROAD DISPATCHING DIFFICULT?

If railroad dispatchers' only duty was to route scheduled trains that arrive on time their task would be straightforward. In those cases the tracks to be used, and the meets (the time and place when two trains will meet) are predefined and routing decisions are routine. What makes dispatching cognitively difficult is dealing with *unplanned demands* on track usage (e.g., the need to accommodate unscheduled trains and requests for time on the track for maintenance work), and the need for dynamic *re-planning* in response to unanticipated events (e.g., train delays, track outages).

Demand on track usage is high, and the margin for flexibility can be low. In passenger operations trains need to be within 5 minutes of schedule, and there are limited routing options available. Further, predicting when a train will arrive can be difficult because it requires keeping track of the progress of multiple trains, some outside the area controlled by the dispatch center. It requires knowledge and consideration of multiple factors that can influence train speed (e.g., the characteristics of the train, the weather, the conditions of the track, the time of day). In addition, dispatcher actions can have impacts at a distance in both time and space that need to be considered in deciding on a course of action.

Successful performance depends on the ability of dispatchers to monitor train movement beyond their territory, anticipate delays, balance multiple demands placed on track usage, 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. Traffic over the radio places particularly high attention demands on the dispatcher. Communications include the need to:

- Answer requests for, and issue train movement and track usage authorization to locomotive engineers, maintenance of way workers 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;

EXPERT DISPATCHER STRATEGIES

Dispatchers have developed a number of strategies that smooth the way for trains to pass through territories more efficiently, and satisfy the multiple demands that are placed on track use. They have developed visual, auditory, and other information gathering strategies that allow them to anticipate requirements for changes to schedules and planned meets early so as 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 need for re-planning. They have developed strategies to (1) extract information about train movement and track activity to support anticipation and planning ahead; and (2) act proactively, taking advantage of windows of opportunity to satisfy the multiple demands placed on track use.

Many of these strategies depend heavily 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 maintenance of way personnel).

Below we describe some of the strategies we observed that illustrate the role of communication and cooperation among multiple distributed personnel in facilitating safe and efficient track usage. A more complete description of dispatcher strategies is presented in Roth & Malsch (1999).

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 usage and plan moves early.

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 they rely on to keep track of train location and delays include:

- the wall panel overview display for trains within the territory of control of the dispatch center.
- alerts from other dispatchers
- verbal radio communication that allows them to keep track of trains beyond the dispatch center territory

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/she wants it on) so that the dispatcher knows which track to expect a train on and therefore what signal switching will be needed;
- 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 he/she wants first. For example if one train will need to turn around right away, the dispatcher will request that train first. An inexperienced person might not know to give you the 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 cross-over 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 radio "Party Line" feature to anticipate and plan ahead. One basis for coordination is the use of 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 your own goals and to recognize when information in your possession is of relevance to others and broadcast it, are important contributors to efficient management of track use.

Dispatchers have developed strategies to extract information from verbal 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 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*: A train conductor will generally tell the locomotive engineer "OK out of New London", by comparing the time to the scheduled departure you can compute train delays.
- *Identifying equipment problems:* By overhearing conversation between a locomotive engineer and the mechanical department, the dispatcher gets early notice of malfunctioning train engines that will need to be replaced.
- *Listening for/heading off potential interactions and conflicts:* Dispatchers listen for commitments made by others that may impact activity in their territory. As example a train may request approval from the dispatcher of an abutting territory to go toward his territory, while the dispatcher may have already given someone else approval to move on the same track in the opposite direction. The ability to listen ahead allows dispatchers to nip potential conflicts before they arise.
- *Listening for mistakes.* An experienced train dispatcher will pick up key information that may signal a misunderstanding, confusion, or error. A case in point is a situation where a MOW person is working on the wrong track. On the rail, it is easy for workers, especially inexperienced ones, to get disoriented and think they are on protected track when in fact they are on unprotected track. 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 oncoming trains and called the flagman to alert him of the error.

Acting Proactively

Not only have dispatchers learned to plan ahead, but they have also learned to be proactive, taking advantage of windows of opportunity to meet the multiple demands placed on track use.

*Strategies to Take Advantage of Windows of Opportunity***.** Dispatchers will act pro-actively to take advantage of windows of opportunity that open up. For example, if a dispatcher knows that a maintenance of way worker needs some time to work on the track, and he sees a window of opportunity (e.g., because a train has been delayed), he will call the person and offer some time.

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 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.

In turn, locomotive engineers will sometimes act proactively to save the dispatcher time. For example, if a dispatcher sends a message over the radio directed at one locomotive engineer, but it is also relevant to others, the others will call in over the radio acknowledging receipt of the message. This eliminates the need for the dispatchers to call them individually.

DISCUSSION

The results reveal that 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 strategies depend heavily on communication and cooperation among individuals distributed across time and space. The ability to "listen in" on communications directed at others and selectively attend to information that has a bearing on achievement of your own goals, and to recognize when information in your possession is of relevance to others and broadcast it, are important contributors to efficient management of track use. Dispatchers' planning and scheduling is proactive, anticipatory and opportunistic – taking advantage of windows of opportunities that arise to satisfy the multiple demands that are placed on track use.

The results reinforce findings from other distributed team domains (e.g., space shuttle mission control, air traffic control, medical operating rooms). They reveal the value of a shared communication channel for providing a cognitively 'economic' means to build a common frame of reference that can support anticipation and contingency planning that is characteristic of high reliability teams (e.g., Patterson, Watts-Perotti & Woods, in press; Smith, McCoy & Orasanu, 1998).

The results have implications for introduction of 'data link' digital communication technology that would shift verbal communication off of the radio to digital communication channels. There was clear indication that the radio channel is now overloaded and that there is a need to off-load some of the communication onto other media. Data link technology provides a vehicle for taking information that is now passed over the radio and transferring it over data lines instead (Ditmeyer & 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. For example long dialogues intended to convey detailed information such as exact location are best replaced by data link communication and would benefit from the availability of visual graphics to provide a common frame of reference and avoid misunderstandings. Furthermore, a radio channel assigned to data communications can carry approximately 20 times as much information as a channel assigned to voice communications. Similarly reading aloud and then repeating back complicated movement authorization forms is time consuming and error prone. Transmitting the information as a visual text or graphical display should reduce radio congestion and may reduce the number of 'read back' errors and other errors of confusion and misunderstanding that sometimes occur during verbal radio transmissions. The final outcomes of utilizing data link technology at this time remain an open question.

At the same time the results of the CTA revealed the importance of the "broadcast/party line" aspect of radio communication that provides a shared frame of reference and allows dispatchers and others working on the railroad to anticipate situations and act proactively. Careful attention should be paid to preserving this critical feature of verbal radio communication in attempts to off-load communication to other media.

While Data link technology is often implemented as a private communication channel where only the specified receiver has access to the information transmitted, this is not an inherent characteristic of the technology. It is possible to envision 'broadcast' versions of data link technology where multiple individuals can access a transmitted message or view common graphical displays regarding real time status of track and train information. For example, Malsch (1999) recently implemented two data link systems: a directed system with no broadcasting capacity and a broadcast system. Both of the broadcast systems included graphical representations of track requests and track usage. The systems were then compared for their effectiveness in a simulated railroad dispatching task of responding to requests for utilizing a section of track. While both versions of data link resulted in more efficient communication as compared to radio transmission, the broadcast version of data link produced better dispatcher performance than the directed data link system on several measures such as train safety.

The results of the CTA also have implications for the training of new dispatchers. The results highlighted the skills that dispatchers have developed that allow them to anticipate demands on track use, to plan cooperatively across territory boundaries, and to act proactively. These are important skills that involve communication and cooperation among dispatchers within a dispatch center as well as between dispatchers and other railroad personnel. Currently these cognitive and cooperative planning strategies are expected to be learned from experienced dispatchers in apprenticeship mode. Simulator-based training could be used to more rapidly bring new trainees up to a high level of performance by providing progressive experience in handling complex scenarios that require applying those skills.

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REFERENCES

Ditmeyer, S. R. & Smith, M. E. (1993). Data Links and planning tools: Enhancing the ability to plan and manage train operations. *Rail International*, April 1993, 69-77.

Malsch, N. F. (1999). Design and Testing of a Railroad Dispatching Simulator using Data-Link Technology.

Masters Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

Patterson, E.S., Watts-Perotti, J., & Woods, D.D. (in press). Voice loops as coordination aids in space shuttle mission control. *Computer Supported Cooperative Work.*

Potter, S. S., Roth, E. M., Woods, D. D. & Elm, W. (in press). Bootstrapping multiple converging cognitive task analysis techniques for system design. In Schraagen, J.M.C., Chipman, S.F., & Shalin, V.L. (Eds.) *Cognitive Task Analysis*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Roth, E. M. & Malsch, N. F. (1999). *Understanding How Train Dispatchers Manage and Control Trains: Results of a Preliminary Cognitive Task Analysis*. Washington, D. C.: U. S. Dept. of Transportation, Federal Railroad Administration (draft in review).

Schraagen, J.M.C., Chipman, S.F., & Shalin, V.L. (In press) *Cognitive Task Analysis*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Smith, P. J., McCoy, C. E. & Orasanu, J. Distributed Cooperative Problem-Solving in the Air Traffic Management System. *Proceedings of the Fourth Conference on Naturalistic Decision Making*, Warrenton, Virginia, May 29-31, 1998.

Vanderhorst, J. (1990). A comparison of Voice and Data Link Communications in a Railroad Environment. Overland Park, KS: Burlington Northern Railroad Company. (NTIS No. PB 90200296)