Preliminary Analysis and Simulation of Railroad Dispatcher Workload

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Railroad dispatch centers increasingly use technology to assist dispatchers as they interact with multiple entities across a variety of tasks to ensure trains and track personnel function safely on an efficient schedule. A railroad dispatcher workload simulation could, therefore, be useful in estimating the impact of new technologies on dispatchers' workload and overall system performance, particularly in the concept generation phase of a systems engineering process. This paper first discusses railroad dispatchers' work analysis based on a large dispatch center and then presents the development of the Railroad Dispatcher Workload Simulation (RDWS), which generates models of dispatcher workload given various settings.

INTRODUCTION

Workload is a key consideration as to where and when to implement new technology into the work environment of railroad dispatchers. Simulation can be a useful tool for assessing workload and providing guidance for implementation of automation at the appropriate phase and function (Laughery, Lebiere, & Archer, 2006). It is especially useful in the concept development stage of a systems engineering process when various human-system architectures are being considered. Early identification of potentially problematic workload areas, both too high or too low, helps to avoid unnecessary redesigns later in the implementation stage.

To develop a workload simulation for railroad dispatchers who have adopted new technologies at their work in the past 16 years, it is important to update previous literature on railroad dispatchers' cognitive task analysis (Roth, Malsch, & Multer, 2001). Thus, we conducted a set of field observations of dispatchers' workflow to describe the following:

1) What kind of tasks are dispatchers doing?
2) How frequently do these tasks happen?
3) How long do these tasks last?
4) Who do dispatchers interact with and how do these interactions influence their workload?
5) What kinds of tools do dispatchers use on tasks?
6) Are there any topics or issues that stand out?

Based on the field observations and information from subject matter expert (SME) interviews, this paper presents the development and initial results of the Railroad Dispatcher Workload Simulation (RDWS), which produces models that estimate railroad dispatchers' workload under various conditions based on utilization—the percent of busy time over some pre-specified period. This method has been used in workload research in similar settings to diagnose appropriate automation function allocations and determine the impact on operator workload (Cummings & Guerlain, 2007; Nneji, Cummings, & Stimpson, In review; Rouse, 1980; Stimpson, Ryan, & Cummings, 2016).

RDWS utilizes a discrete event simulation (DES) model of the task flow and distributions to create stochastic estimates of dispatcher utilization during a work shift. This DES approach is a modification of earlier research simulating the workload of aircraft pilots over the course of a flight from takeoff to landing (Stimpson et al., 2016) and locomotive crew in short-haul railroad operations (Nneji et al., In review). DES has been shown to be useful in estimating operator workload in a variety of environments (Gao & Cummings, 2012; Jun, Jacobson, & Swisher, 1999; Luo, Zhang, & Liu, 2002). RDWS aims to generate workload estimates with varying work contents, including emergency events.

METHOD

To determine typical task loading of dispatchers, two researchers visited a U.S. Class I railroad dispatch center over three days. On Day 1, an experienced chief dispatcher trained the researchers for about six hours on the rules and terms that dispatchers normally use in their daily work at the dispatcher center. The training of a dispatcher would normally consist of 10-week classes followed by 18 weeks of on-the-job training.

Day 2 started with 1-hour training on the actual scheduling interface and a cheat sheet of the symbols dispatchers use. The researchers then rotated in observations of two dispatchers at work from 9am to 11am and again 1pm to 2pm, followed by a 30-minute question-and-answer debrief with the trainer.

On Day 3, the two researchers observed another two dispatchers from 8am to 11am, and rotated for the 1pm to 2pm window, followed by a 15-minute debrief with the trainer. At this facility, dispatchers have three 8-hour shifts. The first shift is from 6am to 2pm, the second shift is from 2pm to 10pm, and the third shift is from 10pm to 6am.

At the time of shift exchange, the incoming dispatcher sits with the dispatcher at the previous shift for 10 to 20 minutes to transfer information, and then another half an hour for the successor to work independently to become familiar with the current volume of traffic. Breaks occur based on individuals' needs. The data collected in this study was on the second shift after the transition was complete. Due to security reasons, no digital recording devices were allowed in the dispatcher center. All data were collected from handwritten notes. The digital clock on the wall provided a time reference for the notes.

Dispatch Operating Environment

A typical large freight railroad organization in the U.S. has up to 300 geographical subdivisions, which could include up to 20,000 road crossing devices, 12,000 signals, and 5,000 power switches. This dispatcher center carries not only freight

 DOI 10.1177/1541931218621156

trains but also passenger trains. Typical loads can include anywhere from 550 and 750 trains.

Each geographical division is supervised by a dispatcher. The mission of a dispatcher is to optimize the mainline rail schedule to maximize efficiency, while ensuring the safety of locomotive crews, maintenance workers working on or near the tracks, and the neighboring communities. In general, dispatchers prioritize must-arrive freight trains (e.g., Amazon/UPS/FedEx transit for air shipment) over passenger trains, and then over coal trains.

Dispatchers in this center sit facing 8-12 monitors (Figure 1). Their tools are often referred to as the Computer Aided Dispatching System (CADS), which are visual representations of the tracks and trains. Each dispatcher is responsible for a section of track, and in this center, each dispatcher supervised an average of 350 miles of track and controlled 8-12 trains in their sections. Dispatcher task load is typically evenly distributed across a team of dispatchers but can spike for single dispatchers in the event of contingency operations.

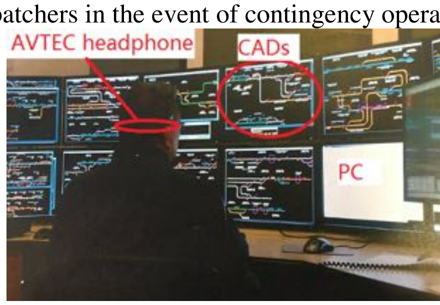

Figure 1. Dispatcher workstation and operating tools

Dispatch Operating Tools

Dispatchers use a set of tools at work, including the following five:

- *Computer Aided Dispatch System (CADs).* A computer visual representation of the tracks and trains that assists dispatchers to safely and efficiently dispatch trains and protect maintenance personnel on tracks (Figure 1).
- *Software and digital forms*. Many forms (e.g., form EC-1, detailed in Table 1) are used to communicate the most updated information between dispatchers and other entities.
- *PC monitors.* Each dispatcher has one or two PC monitors on the side, which can be used to check emails, websites, and find personnel phone numbers.
- *Communication consoles, e.g., AVTEC®,* which is a phone system that connects dispatchers with other people through radios, cell phones, and land line phones through one screen interface. A typical system consists of a headphone, a monitor, and a foot pedal. The phone has built-in speakers and a microphone. The monitor shows contact persons for each railroad station along the assigned track area, the phone queue, the button to connect to the next phone call in line, a dial panel to call out, and a mute button that allows the dispatchers to mute the phone as needed. The foot pedal also has the same mute function.
- *Paper and pencil.* Occasionally, chief dispatchers and intermodal customer service managers may deliver documents (e.g., system bulletins) to the dispatchers' desks. Sometimes dispatchers use a pen to check and highlight items of interest on the paper. This happens infrequently.

Dispatch Center Organization

Dispatchers interact with many people within a dispatcher center, including the following individuals:

- *Chief dispatcher.* Each division has a few chief dispatchers, who are available during each shift. Chief dispatchers make sure dispatchers know the changes of the timetable and train schedules. When dispatchers encounter difficult situations, such as handling conflicting requests of train schedules, they can go to chief dispatchers for advice.
- *Assistant chief dispatcher.* Assistant chief dispatchers assist chief dispatchers in their work, including helping dispatchers when they need advice in scheduling the work authorities for train and tracks.
- *Director of train operations (DTO).* The DTO works in the dispatcher center and oversees the train operations. Dispatchers may also seek advice from them.
- *Intermodal customer service division*. Workers in this division receive phone calls from clients and respond to their complaints and requests about scheduling, but they normally handle the issues within the division, without talking to the dispatchers. When they need to do so, only the manager of the division delivers a message to the dispatchers. In other words, dispatchers do not communicate with clients directly.

Dispatchers also interact with people outside the dispatch center, including the following parties:

- *Locomotive crew.* Each train typically has a conductor and an engineer who communicate with dispatchers regarding train permissions to enter a territory. When maintenance occurs in a territory requiring passing trains to travel at a limited speed, dispatchers will send speed limit requirements via dispatcher messages or EC1 Forms to crew to make sure they comply with the restriction.
- *Yardmasters.* Yardmasters oversee the traffic in the terminal yards because a terminal yard is a complicated optimization and traffic control problem. Conductors of trains going into a yard request permission from the yardmasters, rather than from dispatchers. However, yardmasters communicate with dispatchers to initiate a number in the CADs for a train departing the yard or terminating in the yard.
- *Mechanical team.* The mechanical team crew is responsible for checking engines and repairing trains that break down while en route. They work on the trains upon dispatchers' requests and report the work status when the allowed time expires. If they need longer time to work on a train, they communicate with dispatchers to get permission, also known as work authority.
- *Signal maintenance crew.* Dispatchers have direct control of the track signals to indicate whether trains have permission to go through that territory. When the signal lights go down, dispatchers contact signal maintenance

crew to repair the signal lights. During maintenance, the dispatchers put an order to block that territory to protect the crew working on that track. Signal maintenance crew let the dispatchers know the status of the lights. When the lights are back to normal, dispatchers release the work authority and let trains proceed. When a signal maintenance crew detects malfunctioning lights, they notify dispatchers and request a work authority.

- *Track maintainers (engineers).* Track maintenance crew inspect and repair the tracks. Like signal maintenance crew, track maintainers also need work authority from dispatchers to work on a specific track for protection. The type of protective work authority is also known as maintenance of way (MOW).
- *Public safety coordinators (PSCs).* PSCs go out to the railroad when accidents happen. They report information to the dispatchers and resolve problems, such as cleaning debris, arranging onsite traffic, maintaining the order to keep irrelevant crowds from blocking the workers entering the scene, etc.

Dispatch Operating Rules

The dispatchers follow a set of rules to do their work, which can be generalized into five levels of guidance, listed below from high to low priority (Table 1):

Table 1. Guiding Rules in Decreasing Priority

Rules	Description
#1 East Coast (EC-1) Forms	• These forms have top priority and prevail over other rules. They provide dispatchers with messages regarding the most updated information, for example, if a switch malfunctions or there is some other recent urgent physical change in the environment.
#2 Dispatcher Message	• Instructions and mandatory directives issued by the train dispatcher that govern the operations of trains.
#3 System & General Bulletin, Procedural Instruction Manual	• Written or electronically transmitted special instructions issued by the Operating Rules Department concerning the safety of employees and the movement of trains.
#4 Timetable	• A paper-based book that contains instructions and other essential information relating to the movement of trains or equipment. The Timetable is updated every 2-3 years.
#5 Operating Rules	• A comprehensive guide book about general requirements of dispatchers' behaviors, signals and their usage, movement of trains, etc. This paper-based rules book is the most stable among all five sources.

Dispatchers interact with other people via technologies to ensure trains function safely and efficiently as summarized in Figure 2.

Participants Observed

Four dispatchers (all male) were observed in this case study. Estimated ages were 35, 45, 50, and 60. Experience ranged from 8 to 40 years. These four dispatchers had varying job responsibilities across four different track segments, as detailed below:

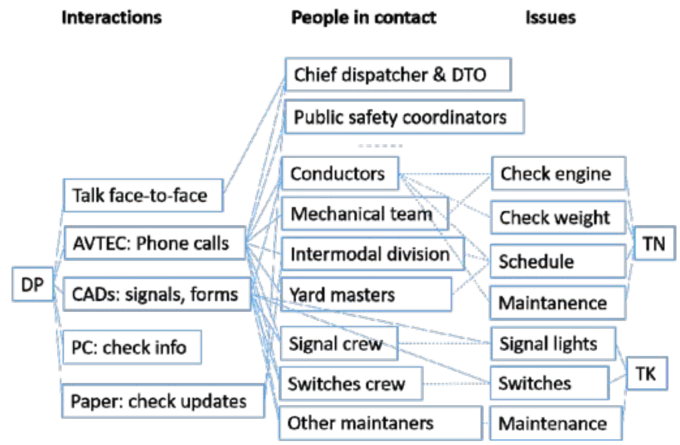

Figure 2. Interactions and peoples involved in a dispatcher's work (DP=dispatcher; TN=train; TK=track)

Dispatcher D1 was responsible for trains and tracks on a mixture of signal and non-signal (dark) territories. In the signal territories, dispatchers have more observability of the tracks and areas they were monitoring and the locations of the trains. They also can control the signal lights in these areas. In the dark territories, where signal lights have not yet been installed, dispatchers cannot tell the exact locations of the train based on any signal exchange, and can only estimate trains' positions within that territory. Therefore, the train conductors and engineers in dark territories are more independent from dispatchers than when in signal territories.

Dispatcher D2 mainly supervised trains and tracks in terminals, also known as yards. Each yard had many trains starting and finishing trips. The yardmasters have direct access to the busy traffic information in the yards, which was not available to dispatchers. Therefore, yardmasters are responsible for overall operations of trains in the yards. Train conductors ask yardmasters for permission to enter a yard, rather than asking dispatchers. Yardmasters communicate with dispatchers about initiating a new train from the yard and request dispatchers to enter that train into the railroad CADs, so that the dispatcher may manage that train after the train leaves the yard.

Dispatcher D3 handled trains and tracks on local tracks and crossroads where pedestrians and cars cross the railroads, making this area of supervision busy. Normally most experienced dispatchers were assigned to these territories due to the complexity of situations, including signal failures, pedestrians' violations of the traffic rules, and accidents. These situations may cause a delay of trains and complaints from conductors and clients.

Dispatcher D4 mainly dealt with trains and tracks where there were no yards (i.e., terminals), dark territories (i.e., non-signal areas), or local crossroads (i.e., pedestrians and cars crossing).

Though these dispatchers managed different types of territories, they used the same tools to interact with multiple entities, described previously, but with different frequencies for various issues. For example, all dispatchers deal with maintenance of way regarding track maintenance issues. All dispatchers have the basic knowledge of all territories because they received formal training on all tasks, which allows them to change positions when they qualify.

RESULTS

To develop a workload model using the data gathered from the field study discussed in the previous section, a set of task interactions was detailed in Table 2. Such interactions are important to elucidate since dispatchers must communicate with multiple entities in their job of optimizing schedules as well as safety for trains and maintenance crews. Dispatcher decision making occurs constantly to generate the best solutions for trains and tracks, with dispatchers communicating with relevant entities about the situations.

Dispatchers used the CADS to make phone calls, change signal lights and switches for the trains, and fill out work authorization forms. Sometimes dispatchers only talked on the phone, while other times they simultaneously filled out a form or check information on the PC while talking. It should be noted that unobservable contents of the call and forms are not listed in Table 2.

Table 2. Observable Task Interactions and Explanations

Observable task	Examples of specific tasks
Phone calls	● Seeking advice from chief dispatchers and other peer dispatchers ● Arranging taxis for train crews who leave the train at the end of a shift ● Performing job briefings to provide maintainers with an overview of relevant track information ● Communicating speed limits on certain track with conductors or arranging the trains to be weighted
Forms	● Form EC-1: A form used to record specific instructions or dispatcher messages from the train dispatchers regarding movements on controlled tracks. ● Form EC-1 Report By: A form under the category of Form EC-1. Conductors report to the dispatcher when they reach a specific location.
Signals	● Lining up trains by clicking signal lights or dragging trains on the CADs screen ● Using signal fleet: giving passing permissions to trains by batch ● Generating new numbers for new trains ● Applying signal stacking/US Stack: pre-arrange multiple trains to go through a segment of track by order of their arrival
Paper & PC	● Check personnel phone number ● Checking daily bulletins ● Taking brief notes on a piece of paper

To develop a discrete event simulation of dispatcher workload, frequent tasks (i.e., more than eight times during the 2-hour observation) were included in the simulation model (see Table 3). Examples of logs observed tasks are listed in Table 4. Calculated task frequency is shown in Table 5.

Table 3. Task Categories in RDWS

Task Category	Explanation
Information Call	Only talking on the phone to exchange information
Form (EC1)	Filling out new forms & reading back when on the phone
Form Release	Receiving phone calls to release an existing EC1 form
Signals	Lining up signals for trains when on the phone, including using signal fleet and US stack function

Table 4. Sample Log Collected during Dispatcher Observation

Start	End	Notes	Task category
10:48:52	10:50:25	New call. EC-1 release. Dispatch messages annulment. He said the original number was…, the new number is […] End.	Form Release
10:50:25	10:54:30	New call. Give a notice. Explained to me that diamond is controlled by local. End.	Information call
10:54:30	10:56:15	New call. Form EC-1. End.	Form EC1

Table 5. Summary of Frequencies of Observed Task Categories per Hour

Sub	Forms	PC	New call	Paper	Ave. time per task	Territory
D1	7.33	3.33	24.00	4.67	0:01:34	Signal & dark
D2	1.00	2.00	16.00	0.00	0:02:11	Normal tracks
D3	6.22	0.00	22.41	0.41	0:01:09	Yard
D4	10.43	2.61	33.91	0.00	0:01:26	Crossroads

Using Matlab®, the best distribution fit was selected based on low square error from common models, i.e., normal, lognormal, uniform, exponential, gamma (see Table 6) (Stimpson et al., 2016).

Table 6. Dispatch Tasks Modeling

Task Name	Arrival Distribution	Service Distribution
Information Call	Lognormal (0.8609, 1.3340)	Lognormal (-0.3306, 0.8074)
Forms (EC1)	Lognormal (2.1018, 0.8769)	Normal (2.1619, 0.8396)
Form Release	Lognormal (1.7478, 1.4859)	Lognormal (-0.4058, 0.5826)
Signals & Train calls	Lognormal (2.5317, 1.1024)	Exponential (1.1733)

Utilization. A dispatcher workload utilization model was created using a combination of the four observed dispatchers and their tasks (Figure 3). It shows a representative utilization profile over time for the combined dispatchers during a notional 8-hour shift controlling a region with 10 trains. Utilization is calculated over 10-minute intervals, represented as individual bars in the figure, indicating the utilization attributed to each of the four task categories during each interval. Engaging in any one of the tasks (e.g., talking or listening on the phone) is considered as full utilization of dispatchers' time. The average utilization for operating ten trains is 68.26%. It should be noted that the utilization model does not explicitly represent unobservable tasks, so these estimates are likely lower than actual workload levels.

In this model, during an 8-hour shift, the dispatcher experienced low workload for 90 minutes, defined as at or below 30% utilization. On the contrary, the dispatcher experienced high workload, defined as at or above 70% utilization, for at least 210 minutes of their shift. Minimum utilization was at 12% for a 10-minute period while several periods of the shift reached 100% utilization. The simulation looks reasonable based on the observation data.

DISCUSSION

To investigate the impact of using improved technologies and automation (e.g., US stacking, signal fleet, and other new proposed systems) on dispatchers' performance and workload, this study conducted a preliminary task analysis for rail dispatchers and a simulation model of their workload. This

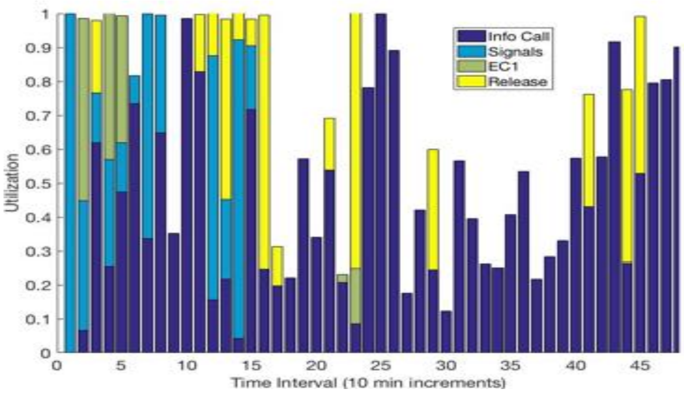

Figure 3. Representative utilization during 8-hour shift

preliminary model, RDWS, showed that rail dispatchers effectively utilized their time in general at 70% across an 8-hour first shift. However, there were periods of low utilization (19%); and even more problematic, the dispatchers' estimated workload was above 70% for ~44% of the time. These results suggest that dispatchers need additional support to reduce their workload during these high periods. Given that automation can sometimes unexpectedly add more work to supervisors of automation, the insertion of various new systems needs to be considered carefully in terms of the impact on dispatchers (Strauch, 2017).

The initial simulation is supported by observations and provides direction for next steps. To refine the model and have subject matter experts validate the model, a few critical issues regarding task identification and classification should be further explored, as listed below.

Task categorization. The task categories in the current model involve a combination of phone calls with additional observable types of interactions. The assumption is that different combinations differ from each other qualitatively. However, since calls constitute the major portion of dispatchers' utilization of time, an alternative approach is to model different calls based on their contents. This work will require understanding the specific issues that dispatcher encounter and the records of all the phone calls, screen activities related the calls, and exact time stamps for each task.

Modeling different territories. Dispatchers in charge of different types of territories (e.g., yardmaster vs. a dark territory dispatcher) may have different focuses, additional work is needed to determine if different types of dispatchers should be represented by different models with different tasks, or rather can such models include the same tasks, just at different frequencies? RDWS can be tailored to any combination of tasks and frequencies so it may be up to the user to specify these differences, but whether there are unique dispatcher roles in their own category remains to be answered. In other dispatch centers, the responsibilities of dispatchers may differ from data at this site. Both similarities and differences should be considered for generalization.

Emergency situations. During observation of dispatcher D3, a train hit a car on the railroad, resulting in the death of the car driver, debris of the car all over the road, and the track and engine of the train were also damaged. The accident led to the delay of other trains after it. The mechanical team contacted the dispatcher to request work authorizations to work on the track. Such emergency events increase the volume of the tasks and the variety of tasks and may lead to extreme periods of workload. These events rarely occur and may be neglected in a generalized model, but dispatchers' readiness to respond to such events is critical. Therefore, an emergency RDWS is also needed to represent these extreme situations.

Future Directions

This initial RDWS model represented four task categories based on four representative dispatchers' first shift at one large dispatch center. Longer observation, system database of detailed contents, data from other shifts and dispatch centers, and data about emergency situations like accidents, are needed to refine the model. Ultimately, this model will be adapted to represent the impact of using improved technologies and automation on dispatchers' performance and workload.

ACKNOWLEDGEMENTS

The authors thank the railroad dispatchers and the organization that welcomed us into their daily operations. While the Federal Railroad Administration funded this project, the findings of the paper do not necessarily represent the FRA's point of view. Dr. Alexander Stimpson and Dr. Michael Clamann helped with model development and observation notes, respectively.

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