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A Systems-Theoretic Computational Model of Human Performance in an Advanced Railroad Dispatch Operation

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13. ABSTRACT (Maximum 200 words)

The Federal Railroad Administration sponsored a research team from Duke University to study railroad dispatcher workload in association with automation under various scenarios and task demands. The team developed a computational model to help examine, understand, and predict the effects of the introduction of technology and automation on dispatcher personnel workload. As railroads implement automation through technologies like Positive Train Control, the role of dispatchers could become more significant in rail traffic control and operational management. It may be important to factor in the effects of changes on the performance of dispatchers, as well as train crews, to maintain acceptable levels of safety in operations for individual trains and the broader networked rail system. The Simulator of Humans and Automation in Dispatch Operations (SHADO) was developed as a rapid prototyping tool that allows decision-makers in the industry to test present and future concepts of operations that embed automated and autonomous systems. This report provides a case study of real-world dispatch operations across three shift schedules in both short-line freight rail and commuter rail scenarios. These findings support the use of SHADO in analysis for additional dispatch operations settings.

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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 CONVERSIO

°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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Executive Summary

The Federal Railroad Administration (FRA) sponsored researchers from Duke University to conduct a comprehensive study of railroad dispatchers and use data gathered to develop the Simulator of Humans and Automation in Dispatch Operations (SHADO) in 2017. SHADO is a discrete event simulation tool that allows stakeholders to easily explore how such traffic, technology, and/or human changes may impact dispatcher workload and performance.

FRA is particularly interested in the utility of SHADO for long range planning, in determining what new technologies are needed to improve job performance and the possible system-level impact on job tasks as new technologies are introduced. SHADO could also be passed to original equipment manufacturers (OEMs) and operational users to better forecast and predict for workforce planning and technology insertion. A primary goal of this study is to demonstrate predictive modeling methods so that the rail industry can be proactive in examining the interaction of new and upgraded technologies with the workforce. Such models also provide a form of safety exploration and assessment, as preliminary estimates can be made in terms of operational errors and risk of human and system failures. There has not been a model like SHADO in the history of US railroad operations.

This study included a literature review, field observations, subject matter expert (SME) interviews, and data mining. Once SHADO was verified independently with industry-standard software, the researchers completed a multi-stage validation process with SMEs and data from Rio Grande Pacific Company (RGPC) that built confidence in using it to simulate real-world operations. RGPC is a railroad holding company that dispatches for multiple shortline freight rail operations and a local commuter rail operation. SHADO was used with RGPC's chief dispatcher and operations manager to perform predictive analyses of the impact of potential (1) new levels of automation and (2) expansion of railroad operations on dispatcher workload for all RGPC's shift schedules and dispatcher desks.

SHADO has been released as an open platform online for any industry stakeholder to use as a rapid prototyping tool to investigate human-system performance in a variety of historical, current, and future concepts of operations. This report presents the novelty and usefulness of the model as well as its limitations. Future work is suggested to gather additional industry data to validate the use of SHADO in more dispatch operations settings. SHADO has the potential to reduce the time and costs for stakeholders to form system design decisions that optimize for efficiency as well as safety when considering human factors with increasing levels of automation.

1. Introduction

The Federal Railroad Administration (FRA) sponsored a research team from Duke University to study railroad dispatcher workload in association with automation under various scenarios and task demands. The team developed a computational model to help examine, understand, and predict the effects of the introduction of technology and automation on dispatcher personnel workload.

1.1 Background

The railroad industry needs models of dispatch operator performance. Dispatchers have long been integral to railroad operations and yet not enough work has been published on how changes in technology applied may influence the dispatcher or how the design of dispatch centers may be adapted to optimize safety and efficiency with advanced railroad technologies. To address this gap, this study presents an objective and quantitative approach (Nneji, 2019) by designing a model that allows original equipment manufacturers (OEMs) and policymakers to consider the human factors risks and opportunities in planning innovative transportation system designs.

1.2 Objectives

The first objective of this effort was to provide analysts and industry stakeholders with a description of the method used to design a rapid prototyping tool, the Simulator of Humans and Automation in Dispatch Operations (SHADO), for investigating advanced dispatch operations. This then provided a roadmap for repeatability of this work and will engender trust in the tool's underlying framework.

The second objective was to show how accurate the model was at representing present-day operations of a real-world railroad dispatch center. This evidence of validation should give industry stakeholders confidence in using this tool to model other related operations. Lastly, the research team presents potential human-system performance results for futuristic scenarios that, without this modeling approach, would be too time-intensive and expensive to investigate.

1.3 Overall Approach

This study's modeling processes are well established and used extensively in other operational domains. By the technology readiness level (TRL) convention, the potential modeling methods in general are TRL 6-9. However, the modeling methods have only been used sparingly in rail settings, lowering their TRL for application in rail systems. In addition, they have not been widely used to model human operators in dispatch centers or the interactions with individuals on a locomotive.

Modeling the technologies, the individuals, and the team processes inside a locomotive and dispatch/operations center requires an approach that includes high-level system behaviors (i.e., global behaviors) as well as the behaviors of individuals (i.e., local behaviors). Thus, the selection of an appropriate modeling technique depends on the model's ability to capture both local and global processes as well as the interactions between all agents in the system. To properly model a rail dispatch center, this study proposes that a model should have the following attributes:

1. Represent those tasks of an individual crewmember or dispatch operator, particularly in terms of time on task and relationship to other tasks (i.e., the temporal ordering of tasks).
2. Reflect both actual and organizational constraints in the system, i.e., regulatory and other operational constraints dictated by the OEM.
3. Be able to estimate the workload of an engineer or dispatch operator at any point in time.
4. Represent the potential for human and system failures in the locomotive and dispatch center as well as the potential loss of situation awareness and fatigue.
5. Variability in human capabilities should be represented.
6. The dispatch model should build from the individual train/engineer models so that it represents the network of trains supervised by a dispatch operator.
7. Represent the workload of multiple dispatch operators and reflect dynamic changes in the system in terms of human workload.
8. Estimate performance metrics of the system (i.e., schedule adherence) as well as individual metrics.
9. The model should include the ability to represent new system capabilities (e.g., PTC) to reflect how changes in the system affect safety and efficiency.

Researchers developed a computational model that embodied these nine attributes and provided a modeling tool that with descriptive and predictive data analytics. FRA, OEMs, and railroad network operations control centers can use this tool in long-range planning for technology insertion (e.g., modeling followed by test followed by analysis).

1.4 Scope

The scope of this work was to study and model the job and tasks associated with locomotive crews and railroad dispatchers at a railroad. The model provided task descriptive and predictive analytics for the effects of the technology implementation on those job functions. The focus was a case study at the Rio Grande Railroad in the Dallas/Ft. Worth Texas area.

1.5 Organization of the Report

Section 2 is a literature review and background study of the human factors of dispatch operations. In Section 3, modeling methods are outlined, including a detailed description of the simulation development process. Section 4 discusses the simulation verification and validation processes that built internal and external confidence in SHADO. Readers will learn how to run experiments with the simulation with the input parameters of the SHADO platform. Section 5 presents the operational settings of two prospective case studies, results of human-system performance, and an analysis and discussion of results. Finally, Section 6 concludes by highlighting the novelty, usefulness, limitations, and potential of SHADO for future work.

2. Literature Review

The literature review spanned basic dispatch operations, human factors in dispatch operations, advanced technologies used in dispatch operations, dispatcher job tasks and decision-making. Literature cited and reviewed in those topic areas provided the necessary understanding of the dispatcher job and working environment.

2.1 Background

Railroad dispatchers have been around since at least 1851, when it was reported that a railroad manager issued a telegram using American Morse code on his telegraph to control the movement of trains in his territory (Hungerford, 1946). Since then, like airline dispatchers (Huang, Nneji, & Cummings, 2019), railroad dispatchers have taken on other modes of communication for supervisory control of railroad traffic. As new technologies like the phone and radio developed, the dispatcher's role with these technologies remains paramount.

A report commissioned by the FRA presented a cognitive task analysis (CTA) on the railroad dispatcher role (Roth, Malsch, & Multer, 2001). The work included field observations at dispatch centers and SME interviews. They provided insight into the functions and demands of a dispatch operator and they concluded with recommendations on potential solutions to alleviate challenges.

Roth et al. (2001) listed sources of input for a dispatch operator and found that the locomotive crew and fellow dispatchers were the primary source of up-to-the-minute changing information. Dispatchers maintain a line of communication spurred from reports or requests of the cab crew. A single dispatcher may be accountable to more than one train at an instant and his or her actions ultimately impact the safety and efficiency of railroad operations.

According to Roth et al. (2001), dispatchers face challenges in satisfying multiple demands from crews and others, including maintenance-of-way (MOW), emergency services, and the public. The dispatcher must maintain a large memory bank of tasks that must be revisited to handle an unanticipated request from their networked system that may require immediacy. Although there is a generally established schedule at the start of their shifts, uncertainty must be managed each day.

Dispatchers have a set of responsibilities to maintain supervisory control of their railroad track territory:

(1) Safe mainline train operations:
   a. Adherence to operating rules
   b. Monitoring traffic to avoid conflict
   c. Alerting cab crew in case of emergency

(2) Efficient routing for timely transit of passenger trains

(3) Routing all other trains passing through territory

(4) Safe scheduling of MOW

Under contingency conditions, particularly dark territory, MOW, emergencies, or other exception-handling, there is a sequence of potential tasks a dispatcher could follow:

- Dark territory (regions of railroads that do not have train detection systems or switch systems for dispatchers to remotely monitor and control traffic):
  (1) Vocally communicate with locomotive engineer
  (2) Manually block track to authorize train motion
  (3) Paperwork on movement permission
  (4) Vocally communicate movement permission
  (5) Listen in for completion of movement
- MOW (railroad construction crew):
  (1) Vocally communicate with MOW workers
  (2) Permit track use for MOW
  (3) Block track to authorize MOW work
  (4) Paperwork on work permission
  (5) Vocally communicate work permission
  (6) Listen in for completion of work
- Emergency (unexpected events that disrupt regular operations that are major, time-sensitive, safety-critical and require external services):
  (1) Communicate with first responders
- Other exception-handling (unexpected events that disrupt regular operations but are minor or can be resolved internally):
  (1) Communicate with locomotive engineer
  (2) Communicate with Trouble Desk

Roth et al. (2001) highlighted several gaps to motivate future research:

- Differences in dispatcher performance based on the presence of assistive technologies
- Impact of individual interaction with team structures on a dispatch center's network performance
- Impact of new technologies on dispatcher workload

2.2 Human Factors in Dispatch Operations

Except for some recently published work (Huang, Cummings, & Nneji, 2018), much of the broader research investigating dispatch operations have focused on improving and optimizing the dispatch process through different scheduling algorithms (e.g., Albrecht & Oettich, 2002; Corman, 2010). However, Gertler and Nash (2004) studied optimal manning systems for dispatch centers.

Gertler and Nash (2004) predicted the impact of schedules on fatigue and formed new methods for dispatch operator network scheduling. Gertler and Nash found that several operations centers assigned dispatchers to work regular shifts or overtime as needed for irregular operations that required additional staffing. For example, during the summer season, railroads can expect higher workloads due to generally more MOW interaction than other parts of the year, so additional staff are brought in to augment the dispatcher. This may lead to an atypical work environment in which regular staff desks become split between two dispatchers. The authors defined workload by wait time, number of calls into dispatch, and number of official complaints.

A U.K. team (Farrington-Darby, Wilson, Norris, & Clarke, 2006) performed an ethnographic study and identified features that described the environment and role of dispatchers (termed controllers or signalers abroad). They found that dispatchers primarily performed real-time incident management tasks and commonly had challenges with system monitoring tasks. The authors developed a task diagram scheme, which may be useful input to build in realistic complexity into our discrete event simulation model. They highlighted four overarching work activities:

- Handling queries and general reports
- Projecting delays
- Managing unplanned incidents
- Managing planned incidents

To handle these high-level activities, there was a general four-step process that dispatchers were found to consistently apply in iterations:

1. Receive alert of a possible incident.
2. Search for context of the problem.
3. Create a plan to handle task.
4. Implement plan.

SMEs considered steps 2 and 3 to be the most challenging parts of their job and step 4 the least challenging (Farrington-Darby et al., 2006). For example, to service a request for track use permission that leads to the temporary speed restriction tasks that a locomotive engineer and freight conductor cab crew may encounter, the dispatcher would follow this four-step process:

1. Receive and review request from MOW.
2. Agree to permission terms.
3. Develop plan for service.
4. Communicate plan to MOW and locomotive crew.

2.3 Advanced Technologies in Dispatch Operations

Alongside understanding how human factors affect operations dispatch, another important element critical in understanding the dispatcher's work environment is the impact of new technologies. U.S. railroads have been working to install automated technologies, namely PTC, into operations nationwide since the Rail Safety Improvement Act of 2008. At this writing, companies like GE Transportation, now Wabtec, have been selling fuel optimization systems, or a type of cruise control system, used widely among railroads for energy management. Such systems, combined with PTC, could provide a form of autopilot similar to self-driving cars.

Lenior, Janssen, Neerincx, and Schreibers (2006) reviewed decision support tools that dispatchers use to project train motion. They noted that automation requires a different approach for the dispatcher interface design with awareness of the state space and the computer's decision-making paradigm. In their study, the task of unblocking tracks for Dutch Railways was offloaded onto automation by implementing algorithms to check trains, compare schedules, and confirm multifaceted checks to safely and efficiently manage traffic. The automation operated deterministically, so the human dispatcher needed to remain aware in case of a glitch in the human-system operations.

Given that advanced automation will be increasingly used in both locomotives and dispatch centers, there is a need to better understand how such technologies will impact operations from both an efficiency and safety perspective. While simulation models have been routinely developed to explore such questions in aviation, there has been little work in extending such objective and quantitative approaches to rail dispatch. To address this gap, the next section will outline the development of such a model that allows OEMs and policymakers to consider the human factors risks and opportunities in planning the future dispatch workforce and innovative transportation system designs.

3. Simulation Development

Railroad companies have multiple stakeholders with diverse interests who demand public safety, logistic efficiency, job security, profitability, and technological innovation. With these competing demands, there is a need for a tool to prospectively explore how changes to some variables may influence other important variables. With increasing forms of automation in locomotives and on railroad tracks across the U.S., an objective method for better understanding the potential implications on system performance is needed.

To explore remote dispatcher performance and workload, a model is needed that allows OEMs and policymakers to consider the human factors risks and opportunities in planning the future workforce and innovative transportation system designs. Building from the literature review, the core elements of our Simulator of Humans and Automation in Dispatch Operations (SHADO) are outlined in this chapter.

3.1 Discrete Event Simulation Approach

To model dispatch operations, the researchers adopted the discrete event simulation (DES) modeling approach, as such models have been successfully applied to supervisory control domains including air traffic control (Humphreys, 1998; Loft, Sanderson, Neal, & Mooij, 2007; Majumdar & Polak, 2001; Schmidt, 1978; Tewes, 1999) and single-operator control of multiple unmanned vehicles (Donmez, Nehme, & Cummings, 2010; Nehme, 2009; Nehme, Mekdeci, Crandall, & Cummings, 2009). They have also been used in call center planning (Lam & Lau, 2004; Mazzuchi & Wallace, 2004) and in military command and control settings (Gao & Cummings, 2012). Recently, DES has been extended into railroad operations to model workload of locomotive engineers (Nneji, Cummings, & Stimpson, 2019).

DES models involve queuing-based constructs including events, arrival processes, service processes, and queuing policies to model the human operator as a serial processor of tasks. In this research, the level of task performance measurement is important to ensure the accurate modeling of workload. Task performance is measured and modeled at the level of functional allocation. The input variables are primarily the timing of various dispatcher tasks (set up as arrival rates) and the distributions of task durations (set up as service times). For example, the expected frequency and duration of communication tasks a dispatcher may handle would be drawn with a probability from a distribution based on patterns observed in several related real-world conditions.

3.2 Model Design

In this DES modeling effort, as shown in Figure 1, a simulation of rail dispatcher workload begins with the user-defined input parameters, including number of replications. A replication represents a different day that takes random draws from the same shift parameter distributions. A higher number of replications allows the user to view a wider slate of possible outcomes based on probabilities. Each new day may have some variation in human error probability, the timing of transfer-of-duty periods, the timing of tasks as well as any extreme conditions a user simulates.

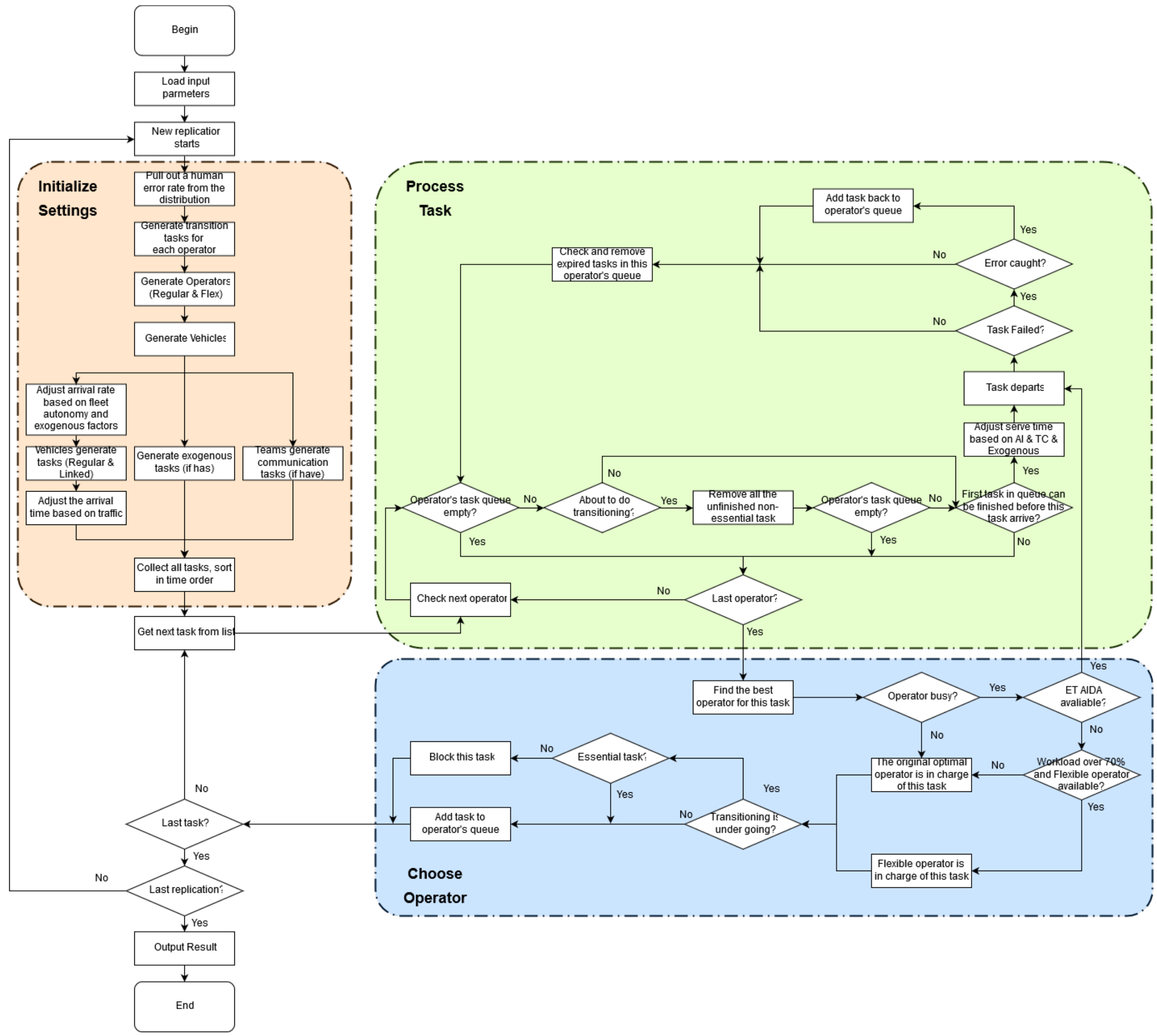


Figure 1. Flowchart of Simulation Runs in SHADO

As a day's shift begins in Figure 1, a task enters the system given an associated probabilistic distribution and then is assigned to a dispatcher's queue. The task awaits dispatcher availability and then leaves the queue to be processed once the operator begins the task. While being processed, the task may be interrupted by another task of higher priority and thus returned to wait in queue until the operator is available. Finally, the task exits the system. At any point in this process, the task may expire before completion, at which point it exits the system prematurely. The task may also go unfinished if the last transfer-of-duty begins or the shift ends. Certain types of phone calls cannot ring endlessly so they can be modeled with an expiration.

For each dispatcher in a shift, the simulation tracks several different statistics. Utilization, the principal measure, is used as a proxy for workload. It is defined as the percentage of time an operator spends on task performance out of the total operation time. The simulation records the utilization for each dispatcher in 60-minute intervals and presents the distribution across the number of replications computed. Utilization is an important statistic because decrements in human operator performance are more likely to occur when utilization is below 30 percent and above 70 percent (Cummings, Gao, & Thornburg, 2016; Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013; Cummings & Nehme, 2010; Rouse, 1983; Yerkes & Dodson, 1908). The statistics SHADO records are summarized in Table 1.

Table 1. Simulation Output Statistics

Output Statistic	**Description**	**Purpose**
Utilization	Time on task divided by total (60-min.) time interval.	Identify workload of dispatcher.
Average Wait Time	Average time each task waited in the operator's Queue.	Identify delays in system operations.
Missed Tasks	Tasks not started by the dispatcher.	Identify insufficiency in dispatch operations staffing.
Incomplete Tasks	Tasks started but not completed by the Dispatcher.	Identify ineffectiveness in dispatcher performance.
Caught Failed Tasks	Tasks completed incorrectly and repeated.	Identify inefficiencies in dispatcher performance.
Uncaught Failed Tasks	Tasks completed incorrectly.	Identify riskiness in dispatch operations design.

The specific implementation of the design is described in the following subsections.

3.3 Model Parameters

The model makes the following simplifying assumptions:

- *Dispatchers as serial processors*: An operator can service only one task at a time.
- *Dispatcher fatigue*: The homeostatic fatigue model discussed in Appendix A (Hursh et al., 2004) was incorporated here in that the service time for each task is multiplied by the appropriate fatigue factor depending on the time it arrives into the dispatchers' queue for processing such that there is a 1 percent increase, per hour, in how long it takes each dispatcher to complete tasks.
- *Same service time distribution between dispatchers*: A task's service time is drawn from the same distribution regardless of the type of dispatcher completing the task.
- *Three types of artificial intelligence decision aids*: (1) Agents that assist individual dispatchers reduce dispatcher's service time on associated tasks by 30 percent (partial assistance) or 70 percent (high assistance); (2) agents that assist types (teams) of dispatchers reduce internal coordination time by 50 percent; (3) agents that assist fully in dispatcher task performance can handle any task completely at the same, better or worst speed, and accuracy as dispatchers on same desk.

- *Types (teams) of dispatchers*: A dispatcher may share the same desk with other dispatchers, and they may have no, partial, or high levels of coordination. Partial levels of coordination mean that they have internal communications tasks that arrive on an exponential distribution of once every 10 minutes, lasting an average of 10 seconds. High levels of coordination mean that the team communicates once every 5 minutes. Coordination also leads to greater chances of catching a human error at the desk: 30 percent more likely with partial and 70 percent more likely with full.
- *Subdivision-to-subdivision radio communications*: A railroad with some level of local radio communications would demand less from a dispatcher. Partial levels of local communications reduce the rate of task arrivals by 30 percent while high levels of local communications reduce the rate of task arrivals by 70 percent.
- *Derailment*: Dispatchers working during a shift with a train derailment have an off-nominal essential task that lasts anywhere from 20 to 40 minutes, arriving, on average, once every 8 hours of their shift.
- *Poor weather*: Dispatchers working during a shift with poor weather will have all tasks that are affected by weather arrive 10 percent more frequently into their operations system.

These assumptions help simplify the complex system but result in some limitations (see Section 6.3). Users have the option to force derailment and/or poor weather to simulate how such irregular events may be handled under different system configurations.

4.3.1 Conditions of Shift

SHADO allows for several factors as inputs for the rail dispatcher shift:

- *Hours*: The number of hours that the dispatchers are working this shift.
- *Transfer-of-duty periods*: The timing, if any, of shift transfers between outgoing and oncoming dispatchers. This can be at the beginning and/or ending of their shifts. Users can include their estimation of how long it takes for the shift transfer using exponential, lognormal, uniform, triangular probability distributions or constant values.
- *Extreme conditions*: The type of off-nominal issue that would spike dispatcher workload. In this case, derailment and poor weather are options.

4.3.2 Characteristics of Tasks

SHADO can represent various dispatch tasks (from 1–15) at the discretion of the modeler. In this model, there are 10 default task types: *Actuation-OK, Actuation-Clear, Daily Operating Bulletin, Temporary Bulletin Issues, Other Communications, Weather Recording, Notetaking, Reporting, Miscellaneous,* and *Shift Transfer,* as described in Table 2 below.

Actuation tasks can be of the type OK or Clear. The former occurs when a dispatcher responds to requests for authority on portions of railroad track and issues a track warrant to rout trains and other moving track vehicles (Reinach, 2006). The latter occurs when a dispatcher responds to a notice from the train or track crew that their warrant can be canceled safely to allow for others to use. Daily Operating Bulletins are written records of all the temporary bulletins that are relevant for the oncoming day of operations.

Table 2. Dispatcher Tasks

Task Types	*Task Description*
Actuation (OK)	Issuing track warrants
Actuation (Clear)	Clearing track warrants
Daily Operating Bulletin	Summarizing temporary bulletins
Temporary Bulletin	Issuing, voiding, or verifying temporary bulletins
Other Communications	Issuing advisories, coordinating crews and others, handling emergencies
Weather Recording	Recording weather conditions at 6-hour intervals on train sheets
Notetaking	Storing abridged data to quickly refer to as needed at work
Reporting	Recordkeeping of train trip information, delays, consist
Miscellaneous	Personal time while at work
Transfer-of-Duty	Review current bulletins, track warrants, operational issues

Temporary Bulletins involve both phone and paperwork tasks via online forms that a dispatcher must answer as they are notified of changes in the railroad that may influence operational decision-making and safety. Other communications include when a dispatcher must issue advisories (for example, weather, traffic, track condition, speed restrictions, slow orders, bulletins), coordinate between train crews, other dispatchers, supervisors, chief dispatchers, police, crew callers, yardmasters, electric traction power managers. They also have the occasional wrong call and are required to handle emergency notifications (including automatic warning device failures and other calls from the public).

The weather recording tasks come from CFR 49, Part 228.17 rules on a *dispatcher's record of train movements*. At 6-hour intervals a dispatcher shall record weather conditions for each dispatching district under their direction and control. This type of task is handled once by two dispatchers and twice by one dispatcher on an 8-8-8-hour rotation of shifts over the course of one day.

Dispatchers perform notetaking tasks at their discretion, depending on individual needs to record information for quick reference. Reporting, however, is mostly mandatory and is expected to be reviewed by other people from the government (i.e., 49 CFR 228.17) or customers that hired the dispatching service for their railroad. We also count the time dispatchers spend on miscellaneous tasks that are not directly related to their railroad operations (for example, taking a bathroom or smoke break). And at the beginning and end of each shift, dispatchers typically transition by sharing any relevant information to the dispatcher who is taking over their duty.

Each task has the following attributes:

- *Source*: Does this type of task arrive from the railroads or from other sources? An example of one that arrives from other sources would be miscellaneous tasks.
- *Weather*: Is this task affected by weather?
- *Traffic*: Is this task affected by traffic?
- *Team coordination*: Is this task affected by team coordination?
- *Essential/interruptible*: Is this task essential? If not, is this task interruptible?
- *Frequency*: How frequently does this task occur for a dispatcher? E.g., on average, once every X minutes +/– Y minutes. The distribution from which a task's inter-arrival time is

drawn. This time can then be used to determine the arrival time, or the time at which the task enters the system.

- *Expiry*: When this task appears, how much time can it wait to be completed before it becomes invalid? The distribution from which a task's expiration time is drawn. The expiration time is the time at which a task will expire or synonymously the time by which it must exit the system, e.g., it can wait the whole shift time.
- *Service time distribution*: How long does it take a dispatcher to complete this task? The distribution from which a task's service time is drawn. The service time is the total time required for an operator to process the task, e.g., X to Y minutes.
- *Generic task type (GTT)*: What is the nature of this task in terms of experience? E.g., completely familiar, well designed, highly practiced, and routine. Depending on the GTT coded, this task is linked to a human error probability from an associated triangular distribution. This will be discussed in detail later in the validation section.
- *Follow-up tasks*: Are there any tasks that must be followed up with this task? This creates a new task with an arrival rate dependent on this original task's arrival. In SHADO, there can be up to 10 types of follow-up tasks per original task.
- *Dependent inter-arrival time*: When an original task arrives, how much time passes until this task follows? E.g., on average, X minutes after an original task arrives.

4.3.3 Settings of Railroads

SHADO can represent different railroad attributes, including:

- The number of subdivisions on the railroads
- Do these railroads have some level of subdivision-to-subdivision communications?
- Which tasks are associated with these railroads?
- Are there different traffic levels during this shift for these railroads?

4.3.4 Attributes of Dispatchers

In addition to the task types a dispatcher is expected to execute, SHADO also can represent various attributes associated with different types of dispatchers, including:

- Is there a chief dispatcher who can handle any task from any railroad? If yes, how many of these chief dispatchers are on duty this shift? This flexible dispatcher is available to assist all types of dispatchers whenever their workload is above 70 percent.
- How many dispatchers of this type are on duty together?
- Do these dispatchers need to coordinate with each other? No, partial, or high.
    - Partial: Communicate with dispatcher team, on average, once every 10 minutes for an average of 10 seconds each time.
    - High: Communicate with dispatcher team, on average, once every 5 minutes for an average of 10 seconds each time.

- Which tasks and/or railroads do this type of dispatcher handle?
- Which strategy does this type of dispatcher employ to allocate their attention?
  - First-in, first-out: This type of dispatcher handles tasks in chronological order of arrival.
  - Shortest task first: This type of dispatcher handles tasks in order from lowest service time.
  - Priority: This type of this dispatcher handles tasks based on their order of importance. Tasks that are essential are the highest priority. Other tasks can range from high to moderate to neutral to somewhat low to not a priority. Essential tasks always rise to the top of the queue. Essential tasks cannot be interrupted.
- For every task that is completed incorrectly, what is the chance that this type of dispatcher would catch their error?
  - For example, X out of every 10 errors on this type of task
- Which types of advanced dispatch support system, if any, are employed?
  - Backup artificially intelligent agent (BAIA): This agent can handle any task that this type of dispatcher handles. This agent is employed when the humans are unavailable, and a task arrives.
    - How much faster or slower does BAIA complete tasks compared to humans?
    - How much more or less likely would BAIA complete this task incorrectly compared to humans?
    - How much more or less likely would BAIA catch its error compared to humans?
  - Task assistance artificial intelligence agent (TAAIA): This agent directly supports dispatchers of this type by reducing how long it takes them to complete selected tasks. It also reduces the human error probability with each.
    - Which tasks does this agent assist humans with performing?
    - What level of TAAIA is present to speed up human performance on the tasks?
      - Partial: 1.4 times faster. This represents a decrease in 30 percent of service time on each task that this AI assists the human operators.
      - High: 3.3 times faster. This represents a decrease in 70 percent of service time on each task that this AI assists the human operators.
  - If there is some level of team coordination, then the option for an internal dispatcher coordination artificial intelligence agent (IDCAIA) is made available: This agent is only relevant for when there is more than one dispatcher handling

the same desk during the same shift. IDCAIA would reduce the time it takes to communicate internally by 30 percent or 70 percent.

- What level of IDCAIA is present to speed up team communication?
  - Partial: 1.4 times faster
  - High: 3.3 times faster

The human error probabilities (HEPs) used in SHADO were derived from work published by the Rail Safety and Standards Board (Gibson, 2012). Gibson, supported by Network Rail, the Association of Train Operating Companies, and the UK London Underground, developed a technique for quantifying human error in the railway industry. Although the analysis focused on locomotive engineer tasks, the results have been applied to the context of dispatchers. This is a noted limitation and needs further future research.

The 10 default dispatcher task types identified in Table 2 can be described by 6 generic task types (GTTs) with associated triangular distributions of HEP, as listed in Appendix D. GTTs range from skills-, rules-, to knowledge-based tasks (Rasmussen, 1983). According to Gibson (2012), at least 12 and up to 28, usually around 16, in 100 of these tasks are likely to fail and any additional tasks that a dispatcher may have to perform for railway operations at the very least have a 1 in 10,000 chance of failure. With dispatch decision support systems, the event likelihood could be reduced to 1 in 100,000.

This section outlined the structure of SHADO as a computational conceptual model. In the next section, the goals, methods, and results in validating SHADO for use in the real world are discussed.

4. Simulation Validation

A description of the method and process to validate the SHADO model is given in this section. The purpose of validation was to increase confidence in using this tool and that it accomplished what it was designed to do. Validation activity is described in the following subsections.

4.1 Objectives or Goals

Researchers developed SHADO for decision makers to support planning for the staffing and design of dispatch operations in both revolutionary and evolutionary settings. In this section, the results of SHADO's multi-stage simulation verification and validation are presented.

The first goal in this validation section is to increase the research team's own confidence in using the tool to model any operational setting. The researchers wanted to make sure that the code functioned as conceived. Did the model take in input parameters and produce expected outputs? Did the model respond as expected when the team adjusted the internal parameters?

Once the research team had enough internal confidence in how SHADO works, the next goal was to build external confidence, i.e., increasing the confidence in railroad stakeholders using the tool to model real dispatch operations. Did the model get results close to what subject matter experts know of the real world under the same initial settings? Did the model behave realistically when the researchers adjusted the initial settings positively or negatively?

4.2 Methods

According to Law and Kelton (2000), it is important to validate discrete event simulation models to provide a trusted platform for future research and decision making. The following confidence-building validation techniques (explained further in Robinson [1997]) were applied:

1. Input-output and internal parameter verification to validate that SHADO computationally represents our conceptual model.
2. Data validation to ensure that our understanding of the operations and sources of qualitative and quantitative information are accurately represented in the input and internal parameters of SHADO.
3. Open-box validation to inspect and improve the model in parts with subject matter experts.
4. Black-box validation to statistically compare the model's performance with that of historical data from real railroad dispatch operations.

4.3 Results

4.3.1 Input-Output and Internal Computation Verification

It is important to verify that SHADO accurately meets expected system specifications. The team used Rockwell Automation Technologies' commercial off-the-shelf Arena (Version 15.00.00004) computer program to verify the architecture of our stand-alone simulation software, SHADO, which we developed in Java.

The team compared the simulation's performance with Arena's across three input-output variables: (1) task service time, (2) task arrival events, and (3) utilization. For the first two variables, the researchers used the analytical expected value, generated from ideated operations in Appendix A, for service and arrival processes as an initial verification. The team found SHADO yielded results within thresholds +/-4.5 percent of expected minutes of service time and +/-8 percent of expected number of arrival events across the tasks shown in Table 3. Appendix A provides more details on the verification process.

Table 3. Comparison of Mean Value Results from 100 Replications of SHADO versus Arena Simulations

Variable	*Task*	*Mean Value*		
		Target	**SHADO**	**Arena**
Service Time (minutes)	Task 1	2.5	2.59 (+3.6%)	2.5
	Task 2	1	1.02 (+2%)	1
	Task 3	2	1.91 (-4.5%)	1.67 (-16.5%)
Arrival Events (count)	Task 1	42.1	41.98 (-.3%)	40.74 (-3.2%)
	Task 2	17.78	17.71 (-.4%)	17.49 (-1.6%)
	Task 3	2	1.84 (-8%)	1.82 (-9%)

Comparisons with Arena proved useful for verifying that the input-output and internal structure of SHADO was computationally accurate. However, Arena is not flexible enough to allow for fully testing all SHADO's advanced features. Therefore, additional validation using data from the railroad domain is critical. While verifying the ability of SHADO to produce similar results to a commercial-off-the-shelf discrete event simulation package is important for building confidence in model outcomes, the results of SHADO still need to be externally validated in the context of freight dispatcher workload, described in the next section.

4.3.2 Data Validation

The process of validating data gathered for this research occurred in multiple stages. First, the research team interacted with the Rio Grande Pacific Company (RGPC)'s Dispatch Operations Center in Fort Worth, Texas. RGPC is a shortline railroad holding company. RGPC dispatches for 12 shortline freight railroads and one local commuter railroad. The commuter railroad, which operates by centralized traffic control (CTC), covers just 22 miles out of RGPC's over 2,400 miles under management and was required to have positive train control (PTC) installed by 2020.

RGPC is normally staffed with two dispatchers, one for the freight railroads and the other for the commuter railroad. Currently, the chief dispatcher estimates that the dispatcher handling the one commuter railroad already has 75 percent of the center's workload

The team visited the dispatch operations center in January 2018. During that visit, the chief dispatcher gave a thorough overview of the overall operations, introduced individual dispatchers across the morning and afternoon shifts, and allowed the research team to observe and interview the dispatchers in-situ at their desks as shown in Figure 2.

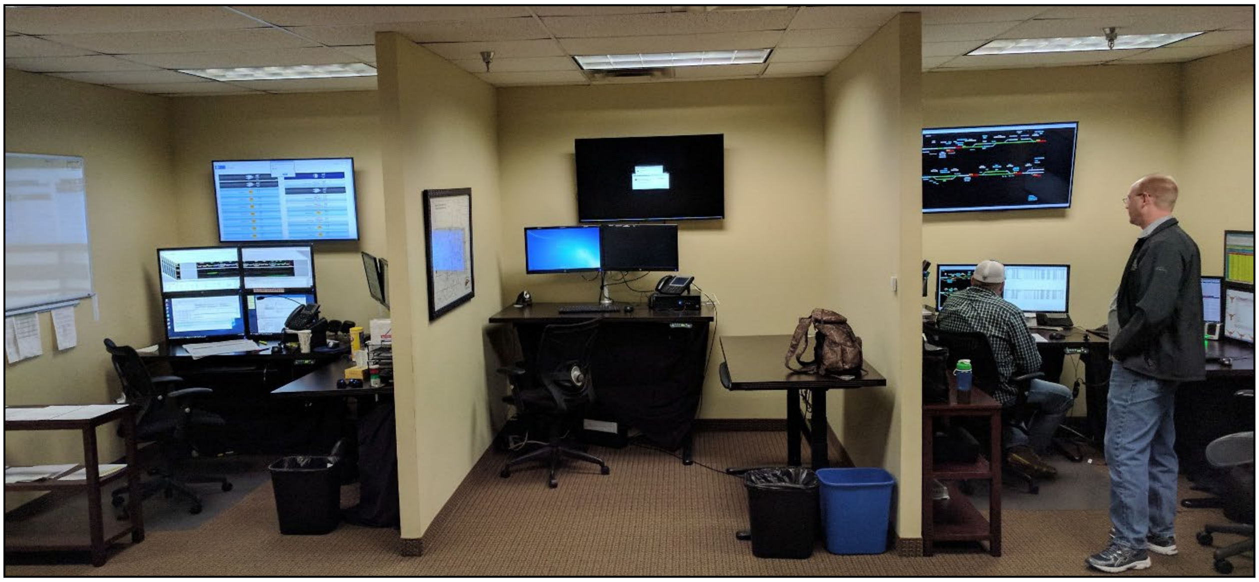


Figure 2. Rio Grande Pacific Company's Two Dispatcher Desks (left: shortline freight; right: local commuter)

During the visit, the researchers identified "talk and listen" (T&L) time as their most critical indicator of dispatcher workload. The chief can record all the incoming calls and calculate T&L time. They gathered documentation (Figure 3) on the shift schedule of the seven dispatchers who work around the clock. Each weekday, two dispatchers work the two desks during the morning (AM, 1st) and afternoon (PM, 2nd) shifts. One dispatcher works both desks during the overnight (ON, 3rd) shifts and for each shift during the weekends.

	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
DISPATCHER	DATE	DATE	DATE	DATE	DATE	DATE	DATE
JOB 1	OFF	1ST	1ST	1ST	1ST	1ST	OFF
JOB 2	OFF	1ST	1ST	1ST	1ST	1ST	OFF
JOB 3	OFF	2ND	2ND	2ND	2ND	2ND	OFF
JOB 4	3RD	3RD	3RD	3RD	3RD	OFF	OFF
JOB 5	1ST	OFF	OFF	1ST	1ST	1ST	1ST
JOB 6	2ND	OFF	OFF	2ND	2ND	2ND	2ND
JOB 7	OFF	2ND	2ND	OFF	OFF	3RD	3RD

Figure 3. RGPC Dispatcher Shift Schedules

From this first visit, the researchers also gathered initial estimates of input parameters and the internal structure of the dispatch center. They validated the task types (Table 2) of the two dispatcher desks. They found that dispatchers on the commuter desk perform functions differently. For example, actuation OK and clear tasks performed via phone and paperwork on the freight desk can be summarized as train movement tasks which are performed by clicking on a computer in advance of a more predictable schedule.

The research team identified arrival times of actuation, train movement, and communication times from the records and formed distributions, as reported in the tables in Appendix B. Appendix C includes a copy of a track warrant form where the researchers gathered the arrival times of actuation OK and clear tasks on the dispatcher desk. They had several follow-up calls and visits to validate the distributions generated for other tasks found during observations and data mining.

Miscellaneous tasks were identified as a missing piece of the original research but critical to realistically simulate how dispatchers use their time. From conversations, the team realized the importance of including time spent going to the restroom or to get fresh air as people in this work environment do not have established break times.

The researchers estimated service times for miscellaneous and other tasks from multiple days of observations in January, March, and May 2018 and interviews with dispatchers from each shift to get a range of possibilities from the spectrum of experiences at each desk. They then interviewed the chief dispatcher to validate the final distributions. They found that the daily operating bulletin task was only performed during the PM shift on the freight desk, whereas there were at least two bulletin tasks per shift on the commuter desk. The transfer-of-duty was estimated to take anywhere from 5 to 15 minutes on the freight desk and last for an average of 5 minutes on the commuter desk, during the beginning and ending of each shift. Dispatchers on the commuter desk were estimated to spend more time on miscellaneous tasks; this can be expected from the nature of their work being more predictable with consistently scheduled train movements than the freight desk.

4.3.3 Open-Box Validation

Open-box validation is a method that stems from white-box validation (Robinson, 1997). To elicit feedback from experts, the researchers designed an open platform to allow us to demonstrate the simulation with a graphical user-friendly interface. They presented the wireframe during a visit to RGPC and followed up with several videoconferences to go through the usability of the interface with the chief dispatcher. The process is shown below, starting with Figure 4. The researchers discussed how they envisioned SHADO being used as described on the platform.

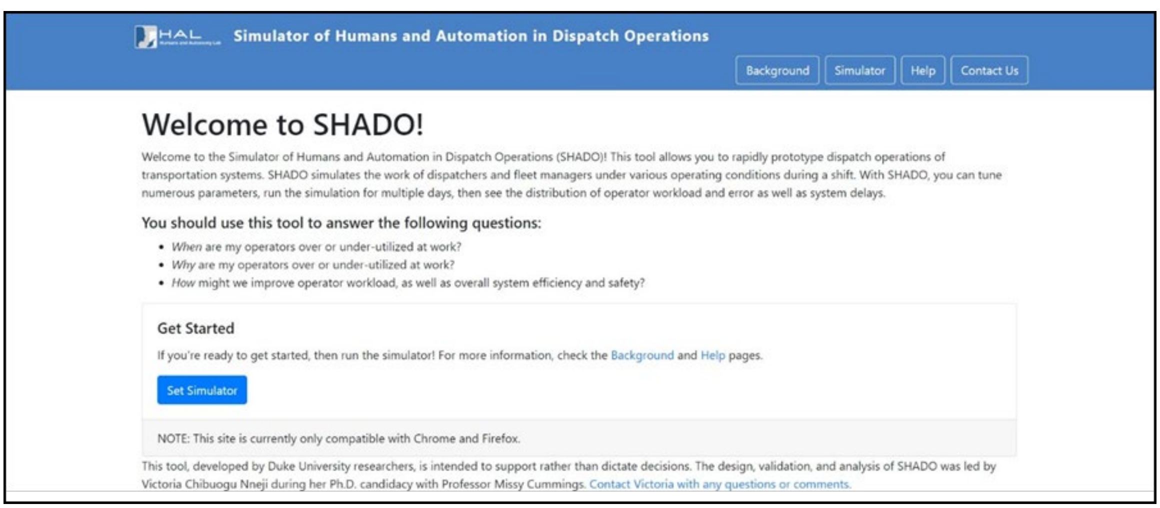


Figure 4. Landing Page of SHADO Open Online Platform

Then, they guided the chief dispatcher through setting up the simulator, as shown in Figure 5.

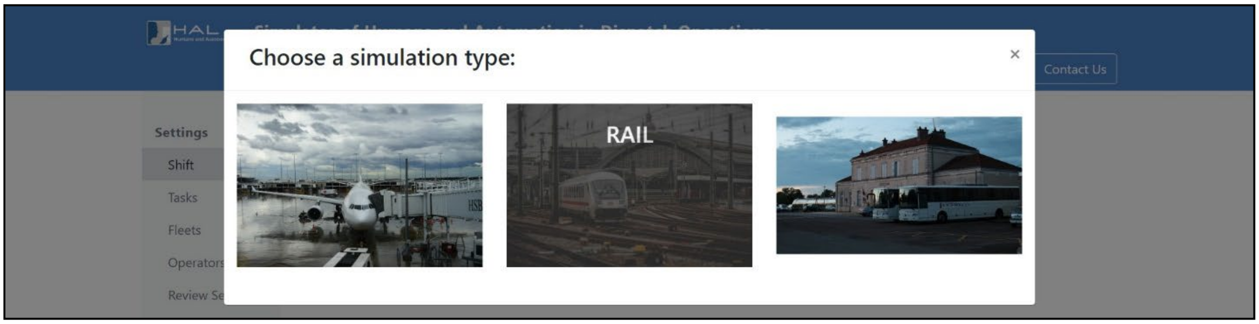


Figure 5. First Step of Set Simulator Page – Choosing a Simulation Type: Air, Rail, or General

Once the chief dispatcher selected the rail domain, he could input parameters of the shift, as shown in Figure 6. The probability distributions from Appendix B, like triangular or uniform, are described in lay terms, and tooltips are included to explain how the model works with certain user choices (e.g., whether a task is essential), as shown in the settings pages in Figure 7, and Figure 8, Figure 9, and Figure 10 are the final pages of settings that allowed the chief to define which task(s) came from which source(s) and which operator(s) would be responsible.

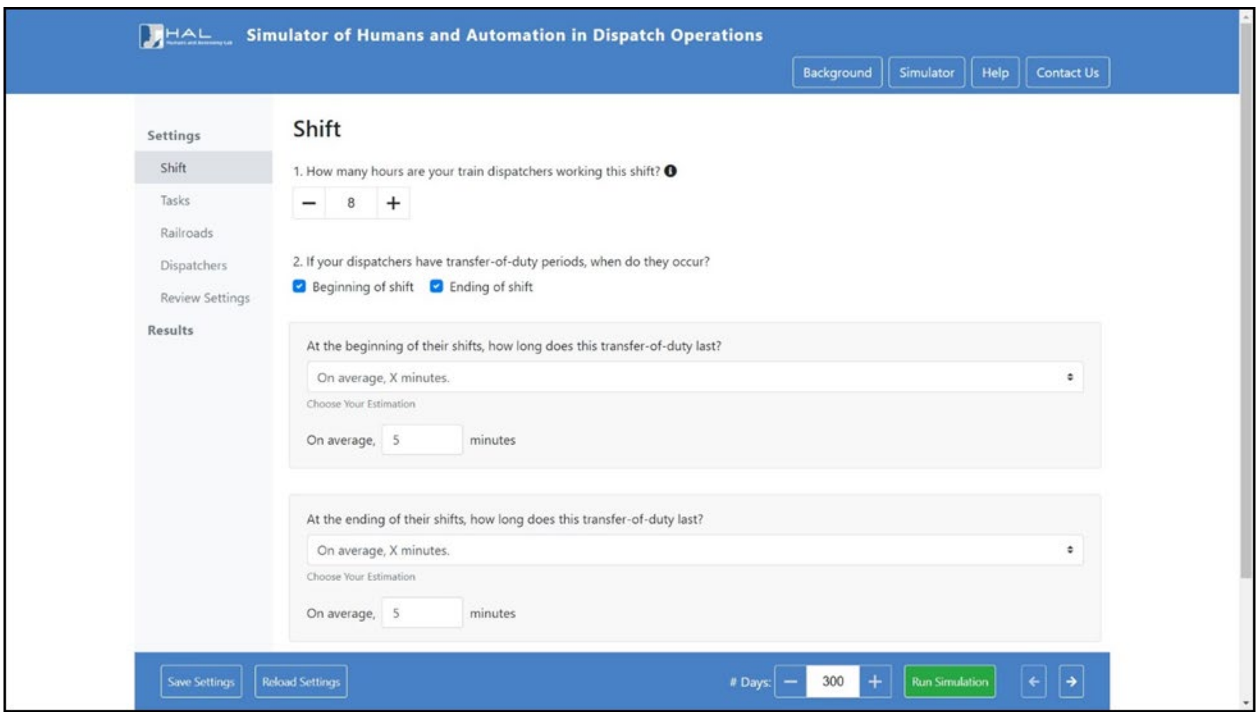


Figure 6. Example of Shift Settings Page

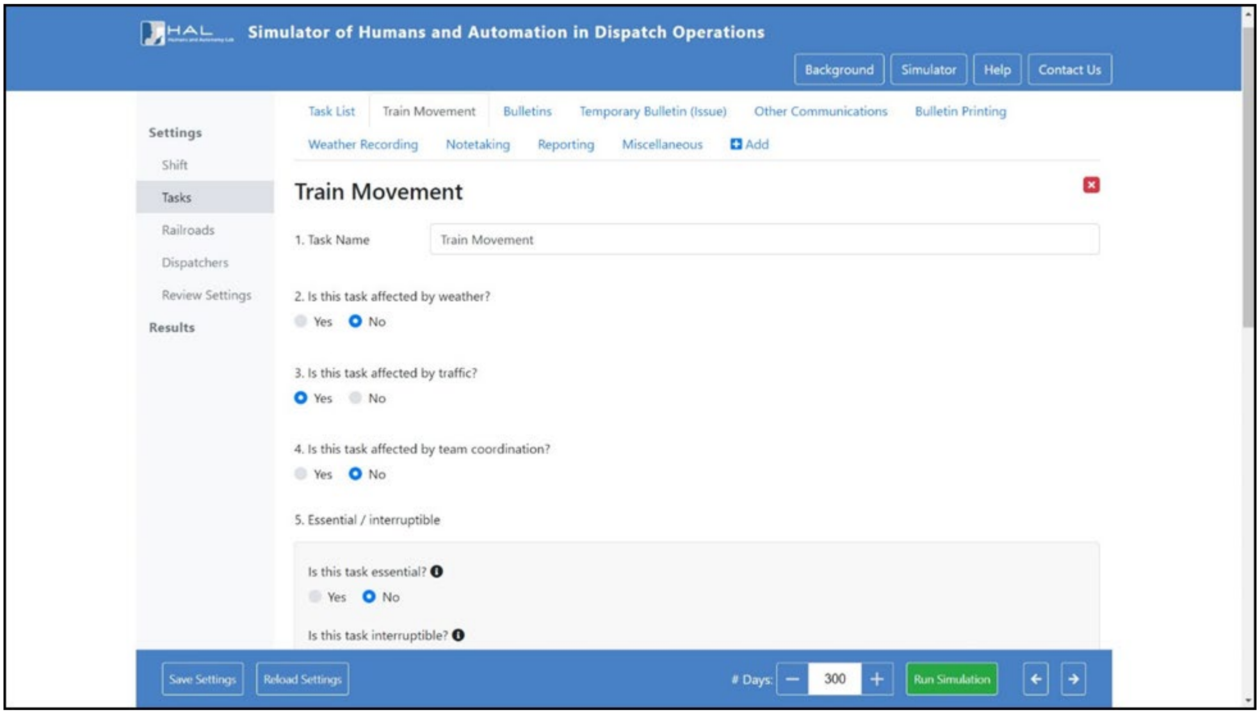


Figure 7. Example of First Section of Task Settings Page for Train Movement Task

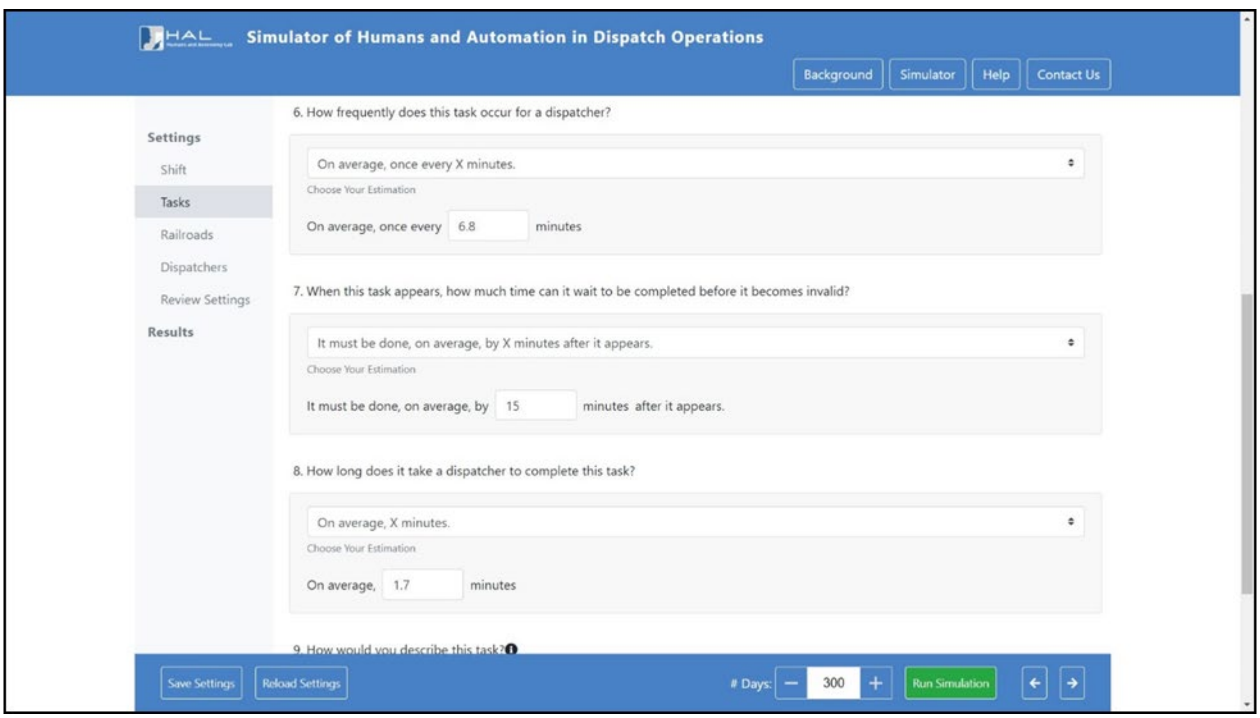


Figure 8. Example of Final Section of Task Settings Page of Train Movement Task

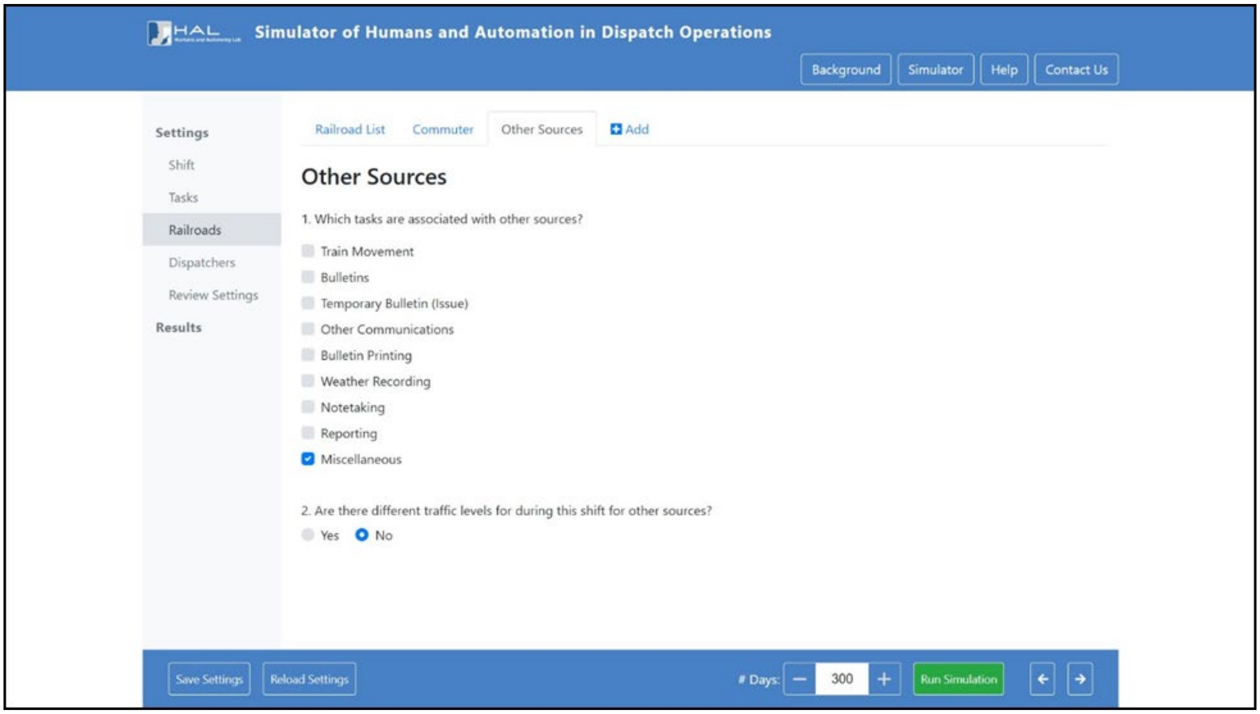


Figure 9. Example of Railroad Settings Page for Tasks from Other Sources

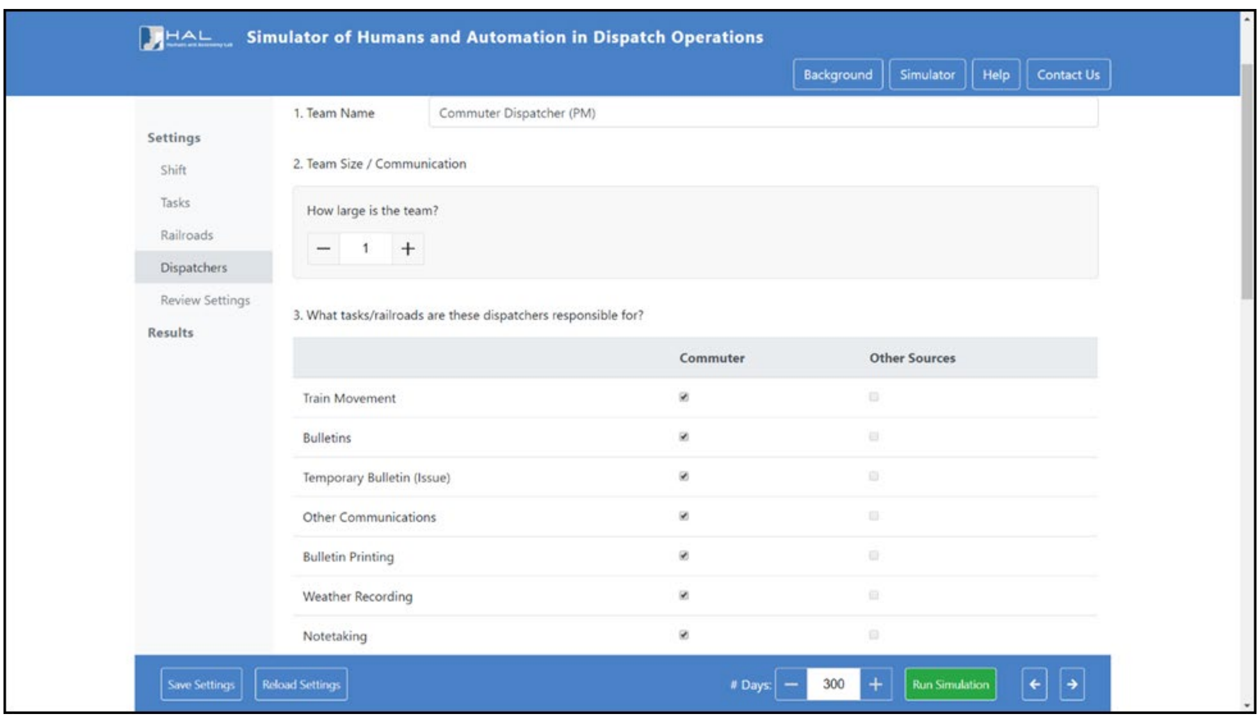


Figure 10. Example of Dispatcher Settings Page for Afternoon Commuter Dispatcher

The chief dispatcher tested different settings of different shifts for the dispatcher desk and could quickly see the results from multiple days of operations. The researchers also created a custom demonstration tool that gave them access to investigate lower levels of utilization in a dynamic stacked bar chart of times on tasks per 10-minute intervals per every day of that shift. An example is shown in Figure 11, Figure 12, and Figure 13 are the high-level results that display the distribution of workload across every hour of every shift, plotted onto a box-and-whiskers plot.

The results also show how busy the operator was on each type of task. Another result included the prediction of how many tasks were completed correctly or with some failure.

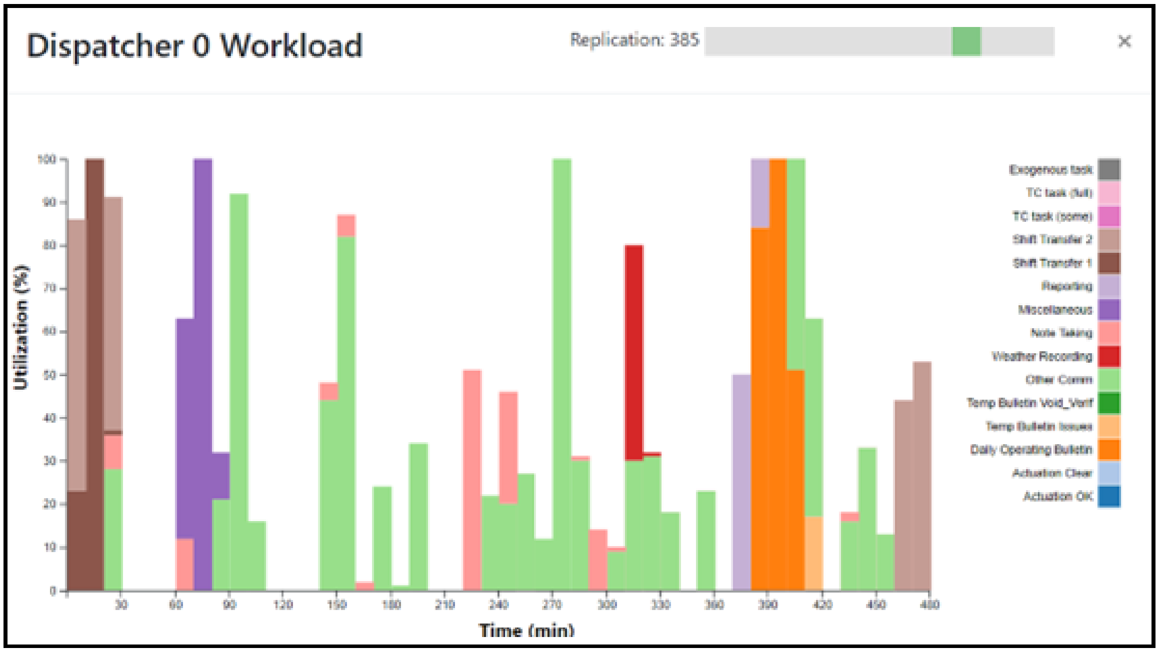
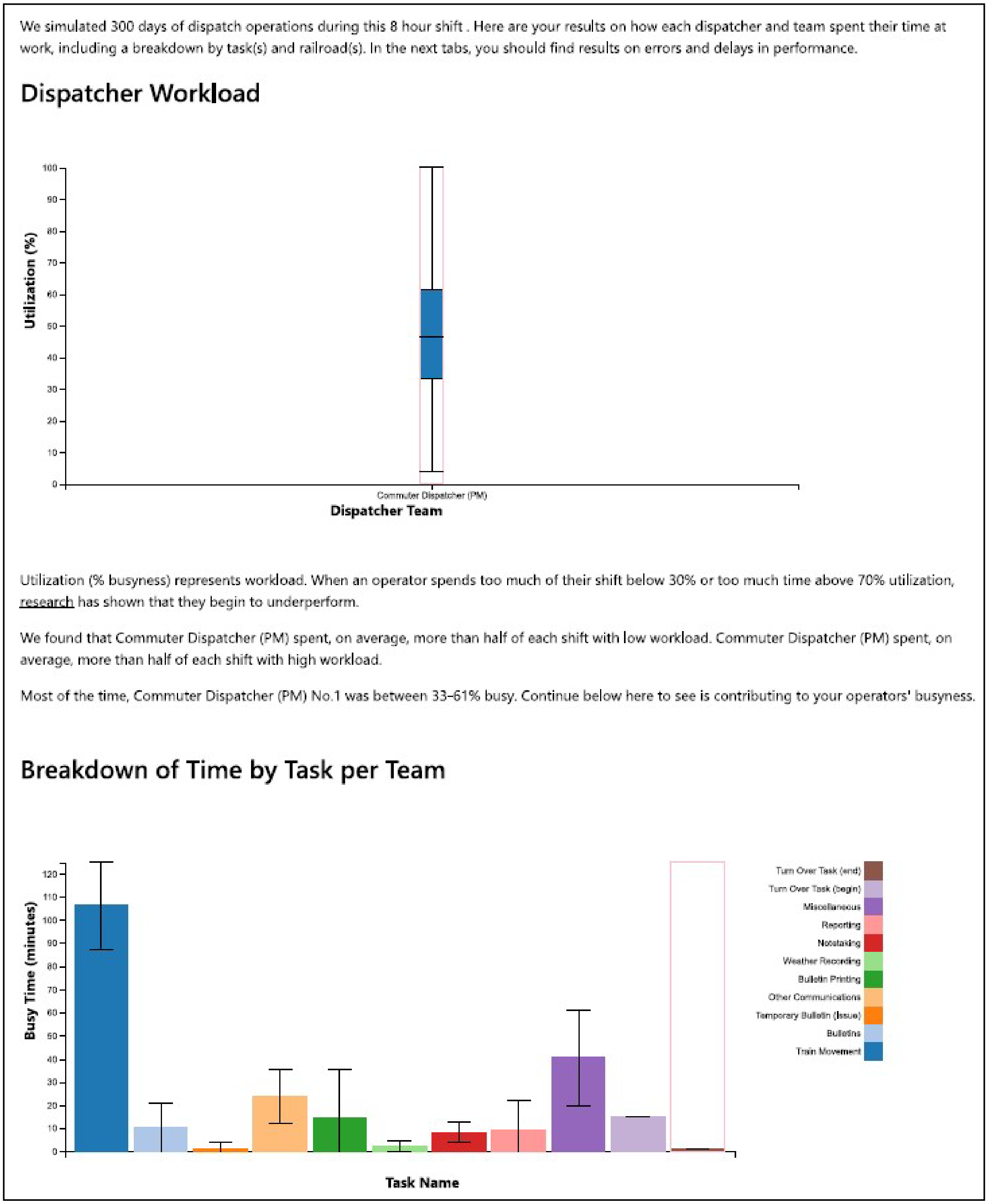


Figure 11. Example of Dynamic Demo of Utilization per Day of Simulation Run



We simulated 300 days of dispatch operations during this 8 hour shift . Here are your results on how each dispatcher and team spent their time at work, including a breakdown by task(s) and railroad(s). In the next tabs, you should find results on errors and delays in performance.

Dispatcher Workload

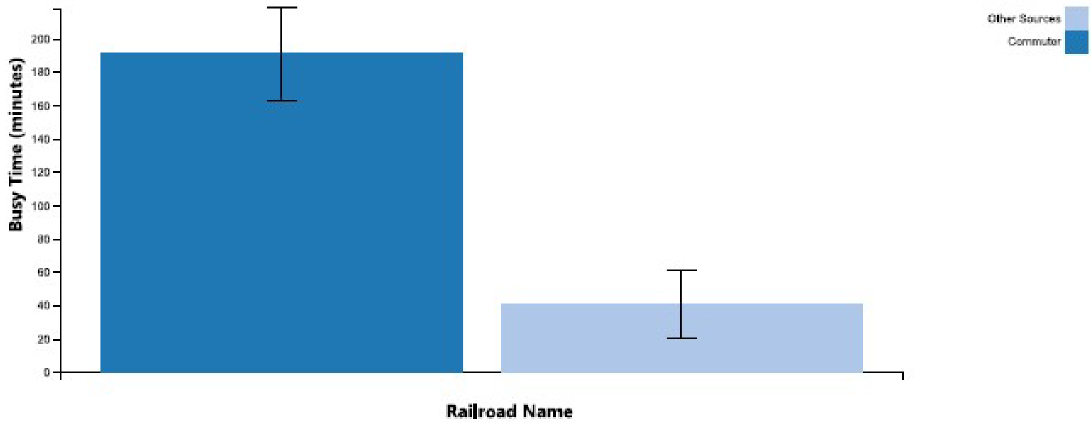
Utilization (% busyness) represents workload. When an operator spends too much of their shift below 30% or too much time above 70% utilization, research has shown that they begin to underperform.

We found that Commuter Dispatcher (PM) spent, on average, more than half of each shift with low workload. Commuter Dispatcher (PM) spent, on average, more than half of each shift with high workload.

Most of the time, Commuter Dispatcher (PM) No.1 was between 33-61% busy. Continue below here to see is contributing to your operators' busyness.

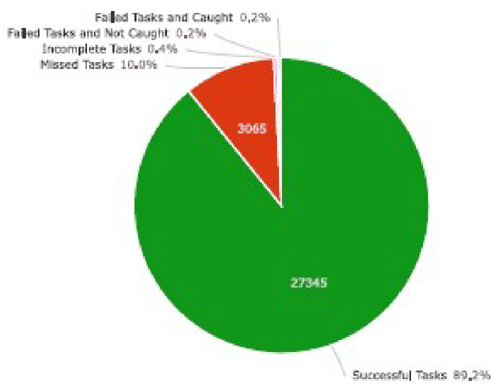
Breakdown of Time by Task per Team

Figure 12. Example of High-Level Results Page of Workload and Time per Task Type



Commuter Dispatcher (PM) spent, on average, more time on Commuter than any other type of railroads. They were least busy with Other Sources.
Commuter Dispatcher (PM) spent, on average, more time on Commuter than any other type of railroads. They were least busy with Other Sources.

Failed Task Analysis



Placeholder for explanation

Filter Team	Filter Task	Missed Tasks			Incomplete Tasks			Failed Tasks and Not Caught			Failed Tasks and Caught		
Dispatcher Team	Task Name	Cnt	Avg	SD	Cnt	Avg	SD	Cnt	Avg	SD	Cnt	Avg	SD
Commuter Dispatcher (PM)	Train Movement	2912	9.71	4.92	54	0.18	0.38	24	0.08	0.30	36	0.12	0.34
Commuter Dispatcher (PM)	Bulletins	51	0.17	0.41	5	0.02	0.13	0	0.00	0.00	0	0.00	0.00

Figure 13. Example of High-Level Results Page of Time per Railroad and Other Sources and Failed Tasks

4.3.4 Black-Box Validation

Finally, to determine the model's ability to describe real-world operations, the researchers used SHADO to replicate the observed empirical results for datasets of T&L time-related operations from morning (AM), afternoon (PM), and overnight (ON) shifts on the freight dispatcher desk. They ran SHADO and compared the results to actual dispatcher utilization results for 6 days x 3 shifts of operations for time spent on actuation tasks, temporary bulletin tasks, and other communications which form the set of T&L time-related tasks. Tables of the raw data gathered from RGPC can be found in Appendix E. They performed a two-sample Kolmogorov-Smirnov (K-S) test using settings presented in Table 4 to investigate whether the distribution of dispatcher utilization from talk-and-listen tasks were the same in simulated and real-world operations of RGPC.

Table 4. SHADO Settings for Kolmogorov-Smirnov Test

Settings	**Input Parameter**
Hours	8
Transfer-of-Duty	Beginning of shift End of shift
Tasks	Actuation (OK), Actuation (Clear), Temporary Bulletin (Issue), Other Communications
Dispatcher Strategy	First-In, First-Out
Dispatcher Error Catching Chance	50% for all tasks
Number of Days	6

The researchers used the MathWorks MATLAB (version R2018a) *kstest2* function, based on foundational statistical research (Marsaglia, Tsang, & Wang, 2003; Massey, 1951; Miller, 1956), which returns a test statistic, the asymptotic p-value, and the test decision for the null hypothesis that the data in the two samples are from the same continuous distribution. The K-S statistic D is defined as the maximum value of the absolute difference between two cumulative distribution functions where each cumulative distribution function is obtained from a list of data points of each sample on which the K-S test is applied. The sample from SHADO is reported in Appendix F. All the D values were found to be less than the critical D-value.

The p-value denotes the level of significance with which the null hypothesis may be accepted. Large p values, as seen in Table 5, imply that the cumulative distribution function of the two samples tested are not significantly different. The confidence that both populations do not belong to the same parent distribution is given by $(1-p) \times 100$. The K-S test shows that the distributions of T&LT-related utilization in simulated and real-world operations of RGPC were as if they belonged to the same parent distribution, as the test rejected the null hypothesis at $\alpha = 0.05$ level of significance.

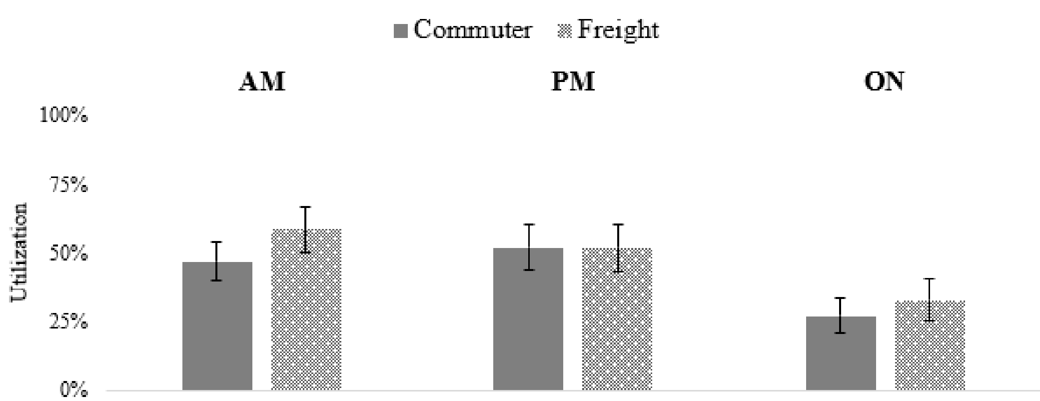
Table 5. Results of Two Sample K-S Tests for Freight Dispatcher T&L Time-Related Utilization

Shift	*D*	*p*
AM	0.1250	0.8220
PM	0.1458	0.6521
ON	0.2083	0.2199

The finding that SHADO was not statistically different from the real-world in the cases of RGPC's freight dispatch operations is strong evidence to support the null hypothesis. This allowed the researchers to be confident in modeling with SHADO. However, they sought a final test to increase that confidence.

The research team asked the SMEs at RGPC to review the output results at each stage of the model development process. After completing verification and other validation steps, the team simulated 300 replications of the default parameters in Appendices C and E. The team presented these results to the chief dispatcher to check how close they matched his experience and expectations of the average workload at each desk during each shift. The results are in Table 6.

Table 6. Average (and Standard Deviation) Dispatcher Workload Simulated with SHADO on Commuter and Freight Desk Data per Shift Schedule



Shift	AM		PM		ON	
Desk	C	F	C	F	C	F
Average	46.8%	58.5%	52.0%	51.8%	27.2%	32.9%
S.D.	7.0%	8.1%	8.2%	8.7%	6.6%	7.8%
Min Average	29.4%	33.7%	31.0%	25.2%	12.2%	17.3%
Max Average	66.2%	82.1%	74.3%	80.6%	49.1%	60.6%

The team asked the chief dispatcher how reasonable the results were under the operational conditions and he agreed on these findings from SHADO:

1. During an average morning (AM) shift, the freight dispatcher desk has more workload than the commuter dispatcher desk.
2. During an average day, the overnight (ON) shift dispatcher has lower workload from each desk.
3. During an average day, the dispatchers on the freight desk have greater variability in hourly workload than the dispatchers on the commuter desk.
4. During an average afternoon (PM) shift, the workload on the commuter and freight desk are comparable, although the dispatcher on the freight desk may have more periods with extreme workload (relatively lower or higher than he would like).

This process of black-box validation allowed the researchers to build confidence in using SHADO to model real-world operations at RGPC. Through quantitative and qualitative approaches, they tested the system and found that the inputs, model design, and outputs make this tool useful. In the next section, SHADO will be utilized to conduct what-if analyses to demonstrate its utility, particularly in better understanding the influence of dispatch center design and operational size on dispatcher workload.

5. What-If Analyses

SHADO can be used to test what-if scenarios and can support stakeholders understand *when* and *why* dispatchers may be over- or under-utilized during a given shift. Such models would be useful in investigating *how* a dispatcher's workload may change with changes in their operations. SHADO can be used to explore how a dispatcher's work could be improved as well as overall system efficiency and safety. Having developed and validated the DES used in SHADO, the next step is to use it to conduct a prospective study of human performance in different system reconfigurations.

On the shortline freight desk, the chief dispatcher was considering options for expanding railroad operations. It was not clear how much RGPC could scale up from managing the current set of 12 shortline freight railroads with their current staffing of one dispatcher at the desk. Hiring a new dispatcher is a long process of recruiting, interviewing, assessing, training, and managing to reduce the likelihood of turnover. Therefore, companies oftentimes are interested in how much more their conventional staff can reasonably manage. Testing this in the real world may take more time and money than they can afford, so SHADO would be the ideal tool to investigate this case of operational expansion after exploring the first case of increasing automation.

5.1 What If RGPC Installs Automation in Local Commuter Rail Operations?

Today, dispatchers at RGPC issue train movement authority via two methods. On the freight desk, RGPC dispatchers issue track warrants via voice-over-radio to their train crews. On the commuter desk, the dispatchers digitally control tracks and signals. In the UK, the commuter desk would be considered a visual display unit (VDU)-based workstation environment.

An independent, structured observational study was conducted in eight dispatch operations centers in Europe (Sharples, Millen, Golightly, & Balfe, 2010). Two observations were recorded with different dispatchers at three VDU workstations at two centers without automation.

Additionally, two observations were recorded of different dispatchers at VDU workstations at four other centers with automation. These observations provided quantitative estimates needed for this study's prospective application of SHADO. The Sharples et al. (2010) study found that automation in dispatch operations led to less time on interaction (i.e., train movement tasks), more time on planning (i.e., bulletin and temporary bulletin issues), less time on paperwork, more time doing miscellaneous tasks, and more time in communications whether that be on phone calls or in the transfer-of-duty periods. Using these results, input parameters were adjusted, as detailed in Appendix G. SHADO was run for 300 days and results were compared for conventional (using default commuter desk settings from Appendix B) versus automated operations with the most likely, best-, and worst-case scenarios. The average utilization results are plotted in Figure 14 and presented in detail in Appendix H.

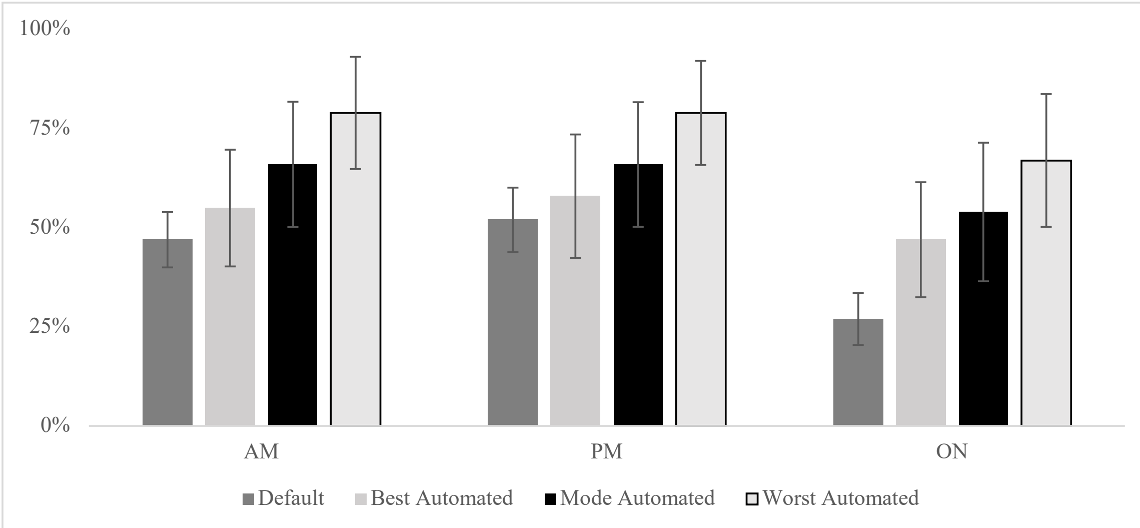


Figure 14. Average (and S.D.) Utilization on Local Commuter Desk per Shift per Scenario

The researchers compared the average utilizations of the default commuter dispatcher desk versus the best and mode automated operations during the AM, PM, and overnight shifts. The results of the statistical analyses are presented in Table 7. The difference between utilization of the commuter dispatcher during conventional operations versus during the most likely case of automated operations in AM shifts was statistically significant. The difference between utilization of the Commuter Dispatcher during conventional operations versus during best-case of automated operations in AM, PM, and ON shifts were also statistically significant.

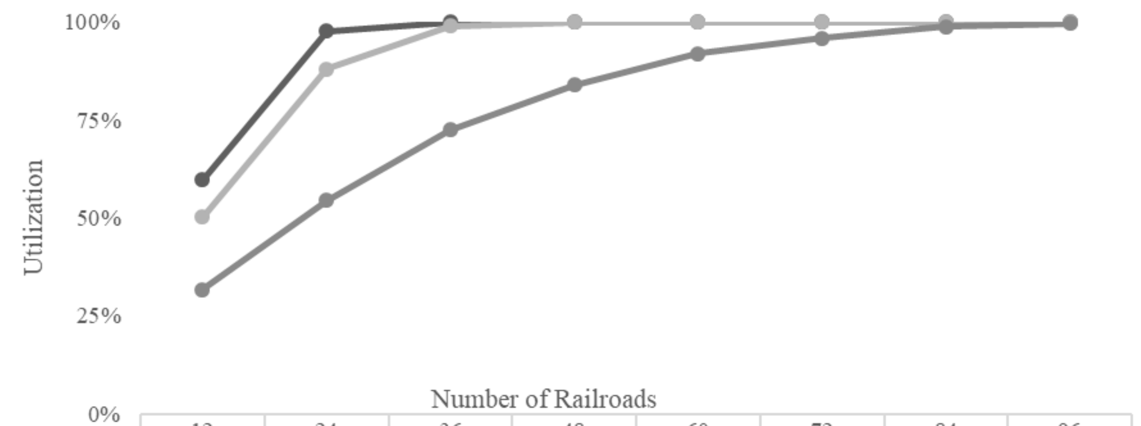
Table 7. Comparison of Means from Default Commuter Dispatcher Utilization

Shift	**AM**		**PM**	**ON**
Scenario	**Mode Automated**	**Best Automated**		
Difference	19.4%	8.4%	5.6%	19.6%
Standard error	0.01	0.009	0.01	0.009
95% CI	0.1746 to 0.2138	0.0659 to 0.1029	0.0361 to 0.0761	0.1783 to 0.2145
t-statistic	19.453	8.963	5.522	21.35
DF	598	598	598	598
Significance level	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001

5.2 What if RGPC increases the size of short-line freight rail operations?

To examine the impact of increasing the size of shortline freight rail operations, SHADO was tuned to multiply, by a factor of size, the average number of task arrivals from the default validated for their current 12 railroads. The researchers ran SHADO for 300 days, using the default parameters presented in Section 4.3.2 for each shift on freight operations. All other variables, except for railroad operational size, were controlled. Table 8 presents results from simulating AM, PM, and ON shifts on the freight dispatcher desk.

Table 8. Average Dispatcher Utilization Results with Increase in Size of Railroad Operations in AM, PM, and ON Shifts on Freight Desk



	12	24	36	48	60	72	84	96
AM	60%	98%	100%	100%	100%	100%	100%	100%
PM	50%	88%	99%	100%	100%	100%	100%	100%
ON	32%	55%	72%	84%	92%	96%	99%	100%

In each consecutive run, the researchers multiplied the railroad operational size from the default 12 railroads to 24 railroads, 36 railroads, 48 railroads, and so on up to 96 railroads on the 8th trial. The freight dispatcher during the morning shift was maxed out by the third trial, during the afternoon shift by the fourth trial, and during the overnight shift by the eight trial.

5.3 Human-Systems Considerations

Although statistically significant results were found in the first scenario, in the context of human factors, the impact of best or most likely cases of automation on performance during the AM and PM shift may not be so significant. The maximum utilization is 100 percent, at which point there are no additional mental resources available for personnel to accomplish additional tasks. The upper bound of workload for optimal operator performance has previously been found at the 70 percent utilization threshold (Cummings & Nehme, 2010; Rouse, 1983). Utilization below 30 percent also presents potential problems for operators since they are operating at levels of work potentially too low. Levels of utilization below 30 percent have been associated with poor performance due to boredom and distraction (Cummings et al., 2016, 2013; Yerkes & Dodson, 1908).

So, on average, the changes in workload for the commuter desk during the morning and afternoon shift, except for the worst-case scenario of automation, may not have a negative effect since the dispatcher would maintain moderate average workload. It appeared that for the overnight shift, additional time on tasks from the new work paradigm may benefit the dispatcher's average workload, increasing it from low to moderate. However, this analysis does not consider how unmanageable this role may be if the one overnight dispatcher manages both commuter and freight rail operations, as RGPC currently staffs today. Overall, these results suggest that increased automation in rail traffic control could increase workload for a dispatcher in this specific setting, but within manageable levels.

Next, the shortline freight rail dispatch desk should ask two questions. First, if RGPC increases the size of freight railroad operations under management, at what point may the dispatcher begin to underperform? And second, at what point might one need to increase dispatcher staffing to handle the increase in operational size at the freight desk?

During the morning and afternoon shifts, the results suggested that, on average, dispatchers could handle up to 24 different railroads, and during the overnight shift, the dispatcher may be able to oversee almost 36 railroads. By the 36^{th} railroad, the morning dispatcher would be maxed out. This would be the case during the afternoon shift by the 48^{th} railroad. On the contrary, the overnight shift results showed that on average, the dispatcher capacity would not reach maximum until 96 railroads. Note that it is not recommended to work dispatchers at these maximum conditions for long periods of time, as human error and other delays may become unreasonable for safe and efficient operations.

These results suggested that adding operations for this specific setting will increase a dispatcher's workload and that additional dispatchers will likely be needed for the morning and afternoon shifts somewhere around 18 railroads. However, a single overnight dispatcher can theoretically handle significantly more, upwards of 48 railroads. It should be emphasized that these interpretations are strictly for this set of dispatch operations, and the model would need to be calibrated for each specific application.

6. Conclusion and Future Work

6.1 Novelty

In this report, we introduced SHADO, the Simulator of Humans and Automation in Dispatch Operations. SHADO is a tool that allows railroad stakeholders to rapidly prototype numerous scenarios. It gives users immense control to design operations centers to meet their specifications with more than 10^18 possible combinations of input parameters. SHADO can simulate historical, present-day and future concepts of operations. The ability to model human performance with results reported on dispatcher workload and error for up to 10,000 days with realistically random distributions each day is a novel contribution to the railroad industry.

6.2 Usefulness

Throughout the model development process, the researchers asked SMEs to review the inputs, the model, and the outputs. These SMEs included the chief dispatcher and four other dispatchers at the RGPC dispatch operations center in Fort Worth, Texas. The SMEs had 1 to 20 years of experience each as dispatchers. The researchers walked through the steps of setting shift conditions, task characteristics, railroads, and dispatcher roles in SHADO, and then explored the results that SHADO produced. The open-box validation process resulted in an online open software platform.

Any stakeholder can access the platform, which has undergone multiple iterations of usability testing. The platform allows users to input custom settings, run multiple scenarios, interact with dynamic data visualizations, save decisions, and download human-system performance results. Stakeholders from RGPC approved the user-friendly design, the usefulness of the underlying computational tool, and the ability it gives them to test ideas that would otherwise be too expensive and time-intensive to try in the real world.

6.3 Limitations

As with any model, there are several limitations of SHADO. First, it requires the user have some representation of the underlying distributions of the task inter-arrival times and operator service times. While this study was able to obtain relatively accurate numbers for the validation tasks, these would need to be updated for every new application of SHADO.

Second, as described in Section 4.3.2, the model sourced human error probability parameters from locomotive crew estimates and not directly from dispatcher estimates. Unfortunately, this study found little data on dispatcher error rates, so there needs to be significantly more research in this area – although the same dataset has been used to model human error in rail dispatchers in Danish operations (Thommesen & Andersen, 2012).

Third, the model does not account for some characteristics of the human operators that could impact performance, such as the hours of sleep prior to the shift. A more complex model that considers other factors, like recent operator work history and shift time of day, along with shift duration, may better provide better predictions for operator workload. However, it was not clear whether the inclusion of such variables would improve model fidelity, so this represents another area of future research.

The results of the prospective analyses are limited in that the input data assumes that the relative effect of automation technology found in the UK are applicable to the U.S., and that new RGPC railroads will replicate the influence of its current railroads. The prospective analyses described in this report can be improved with additional resources to gather more precise data on the nature of PTC in dispatching and on the nature of calls, bulletins, and other sources of dispatcher workload different types of railroads.

Despite model limitations, as has been demonstrated here, SHADO can approximate workload levels for dispatchers with different operational responsibilities and schedules. The internal, external, and face validation with industry standard software, empirically collected data, and SME interviews provide confidence in SHADO's representation of the real-world dispatch operations system. The simulation results were found to be consistent with dispatcher workload trends as experienced by those who have worked directly in rail dispatch operations.

6.4 Potential Uses

One of the goals for building SHADO was to provide a predictive platform to help planners investigate how changes in operations may affect human-system performance. Thus, the research team used SHADO to explore two future scenarios with the shortline freight and local commuter dispatcher desks at RGPC, and so results reported here are limited to this application. More work is required to identify differences in input parameters for larger Class I freight and passenger rail operations. But the potential of SHADO is great, and much of this study's work has proven methods of data collection, model design, and system testing that introduce innovative opportunities for research that have not been explored for railroad operations in the U.S. Moreover, SHADO can be applied to other modes of transportation that similarly rely on dispatchers as railroads have for over a century, and it is a current area of research.

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Appendix A.
Verification of SHADO

This study used the following input settings in both SHADO and Arena. The goal was to ensure that SHADO mathematically computes results not significantly different from Arena across eight different variables with three to four different levels each. For these verification tests, the researchers changed one factor at a time to control for complex interactions. Settings in Table 9 were used for the base case.

Table 9. Initial Input Parameter Settings for Verification Tests

Parameter	Initial Value		
Shift	8 hours		
Traffic	High		
Days	500		
Desks	1		
Railroads	1		
Error-Catching Chance	50%		
Strategy	FIFO		
Expertise	All tasks		
Tasks Generated	All		
Tasks	Task 1	Task 2	Task 3
Arrival Distribution (minutes)	EXPO(60/240)	EXPO(60/11.4)	EXPO(60/27)
Service Distribution (minutes)	UNIF(1,3)	UNIF(2,3)	UNIF(.75, 1.25)
Human Error Probability	0.04%		

The research team tested the desk size parameter by adjusting the number of dispatchers from one to two to three. They tested the railroad size parameter by adjusting the number of subdivisions from one to two to three. They tested the shift schedule parameter by simulation 2-hour, 4-hour, 6-hour, and 8-hour shifts.

The researchers tested the desk expertise by running two simulations each with two dispatchers. The first simulation, with a homogeneous desk where both dispatchers handled tasks from the same queue, and the second with a heterogeneous desk where the two dispatchers each, had separate responsibilities of tasks lined up in their queues.

The research team tested railroad heterogeneity by running four simulations of six subdivisions each. The first simulation had six homogenous subdivisions, all transmitting the same types of tasks to dispatchers. The second simulations had two railroads, one with three subdivisions of Task 1 and the other railroad with three subdivisions generating Task 2. The third simulation also had two railroads, the first with four subdivisions generating Task 1 and the second with two subdivisions generating Task 2. The last simulation modeled three railroads, each with two subdivisions generating Task 1, Task 2, and Task 3, respectively.

The team tested railroad autonomy by running three simulations. The first simulation was with the control variables (no level of subdivision-to-subdivision radio communications). The second was with partial communications and the third with high level of communications. Partial signifies that 30 percent less tasks are generated from this railroad while high signifies that 70 percent less tasks are generated.

The researchers tested the dispatcher strategy parameter by testing a priority strategy, and shortest task first strategy in three different simulations. It tested the extreme conditions parameter by changing the parameter from none to train derailment to poor weather to both. Train derailment generated a new task that lasted longer than other tasks. Poor weather extended the times on all tasks.

Table 10 through Table 17 present results of the verification tests. The average utilization was computed over 500 replications. The max average represents the results of the one replication with the highest average utilization across all the time intervals within that shift. The max represents the maximum utilization value for any one interval across all replications.

Table 10. Verification of Dispatcher Type (desk) Size Parameter

NUMBER OF DISPATCHERS	UTILIZATION STATISTICS					
1	Software	average	max average	min average	max	min
	SHADO	26.42%	36.69%	14.41%	100.00%	0.00%
	Arena	24.68%	40.26%	14.60%	100.00%	0.00%
2	Software	average	max average	min average	max	min
	SHADO	12.44%	19.25%	7.66%	80.85%	0.00%
	Arena	13.22%	18.56%	7.27%	81.64%	0.00%
3	Software	average	max average	min average	max	min
	SHADO	8.33%	12.64%	4.43%	58.44%	0.00%
	Arena	8.81%	12.75%	4.84%	63.24%	0.00%

Table 11. Verification of Railroad Size Parameter

NUMBER OF SUBDIVISIONS	UTILIZATION STATISTICS					
1	Software	average	max average	min average	max	min
	SHADO	24.51%	35.27%	14.73%	100%	0.00%
	Arena	26.42%	40.26%	14.60%	100%	0.00%
2	Software	average	max average	min average	max	min
	SHADO	47.31%	61.33%	37.02%	100.00%	0.00%
	Arena	53.28%	70.79%	39.48%	100.00%	0.00%
3	Software	average	max average	min average	max	min
	SHADO	67.10%	93.60%	56.04%	100.00%	0.00%
	Arena	78.73%	96.83%	59.05%	100.00%	0.00%

Table 12. Verification of Shift Schedule Parameter

HOURS ON DUTY	UTILIZATION STATISTICS					
2	Software	average	max average	min average	max	min
	SHADO	25.90%	49.50%	5.74%	100%	0.00%
	Arena	25.87%	49.54%	9.69%	100%	0.00%
4	Software	average	max average	min average	max	min
	SHADO	25.84%	44.24%	7.47%	100%	0.00%
	Arena	26.25%	46.53%	14.38%	100%	0%
6	Software	average	max average	min average	max	min
	SHADO	26.50%	39.03%	16.48%	100%	0.00%
	Arena	26.35%	39.11%	15.76%	100%	0.00%
8	Software	average	max average	min average	max	min
	SHADO	26.45%	35.96%	17.40%	100.00%	0.00%
	Arena	26.42%	40.26%	14.60%	100.00%	0.00%

Table 13. Verification of Dispatcher Type Parameter

TYPES OF DISPATCHERS	UTILIZATION STATISTICS					
SIMULATION 1, TYPE 1 OF 1 DISPATCHER #1 OF 2	Software	average	max average	min average	max	min
	SHADO	12.50%	18.53%	7.55%	86.80%	0.00%
	Arena	13.30%	19.04%	8.23%	84.21%	0.00%
SIMULATION 1, TYPE 1 OF 1 DISPATCHER #2 OF 2	Software	average	max average	min average	max	min
	SHADO	12.50%	18.53%	7.55%	86.80%	0.00%
	Arena	13.30%	19.04%	8.23%	84.21%	0.00%
SIMULATION 2, TYPE 1 OF 2 DISPATCHER #1 OF 1	Software	average	max average	min average	max	min
	SHADO	23.13%	33.27%	12.99%	100.00%	0.00%
	Arena	22.94%	34.52%	11.03%	100.00%	0.00%
SIMULATION 2, TYPE 2 OF 2 DISPATCHER #1 OF 1	Software	average	max average	min average	max	min
	SHADO	3.81%	6.93%	1.53%	45.03%	0.00%
	Arena	3.73%	6.07%	1.54%	45.35%	0.00%

Table 14. Verification of Railroad Heterogeneity Parameter

RAILROAD HETEROGENEITY	UTILIZATION STATISTICS					
RAILROAD 1 OF 1: 6 SUBDIVISIONS WITH TASK 1	Software	average	max average	min average	max	min
	SHADO	2.51%	5.40%	0.07%	42.42%	0.00%
	Arena	2.47%	5.14%	0.05%	50%	0.00%
RAILROAD 1 OF 2: 3 SUBDIVISIONS WITH TASK 1, RAILROAD 2 OF 2: 3 SUBDIVISIONS WITH TASK 2	Software	average	max average	min average	max	min
	SHADO	6.89%	10.52%	4.59%	53.15%	0.00%
	Arena	6.80%	10.28%	3.89%	45.46%	0.00%
RAILROAD 1 OF 2: 4 SUBDIVISIONS WITH TASK 1, RAILROAD 2 OF 2: 2 SUBDIVISIONS WITH TASK 2	Software	average	max average	min average	max	min
	SHADO	5.47%	8.43%	3.16%	49.55%	0.00%
	Arena	5.36%	8.49%	2.78%	45.38%	0.00%
RAILROAD 1 OF 3: 2 SUBDIVISIONS WITH TASK 1, RAILROAD 2 OF 3: 2 SUBDIVISIONS WITH TASK 2, RAILROAD 3 OF 3: 2 SUBDIVISIONS WITH TASK 3	Software	average	max average	min average	max	min
	SHADO	27.11%	35.21%	18.01%	99.93%	0.00%
	Arena	26.60%	35.38%	18.48%	100%	0.00%

Table 15. Verification of Railroad Autonomy Parameter

LEVEL OF SUBDIVISION-TO-SUBDIVISION RADIO COMMUNICATIONS	UTILIZATION STATISTICS					
NONE	Software	average	max average	min average	max	min
	SHADO	27.04%	41.49%	18.53%	100%	0.00%
	Arena	26.02%	40.26%	14.60%	100%	0.00%
PARTIAL SUBDIVISION-TO-SUBDIVISION RADIO COMMUNICATIONS	Software	average	max average	min average	max	min
	SHADO	19.06%	29.34%	9.82%	100%	0.00%
	Arena	18.54%	26.79%	10.87%	100%	0.00%
HIGH SUBDIVISION-TO-SUBDIVISION RADIO COMMUNICATIONS	Software	average	max average	min average	max	min
	SHADO	8.10%	15.23%	3.16%	99.77%	0.00%
	Arena	7.89%	15.11%	2.76%	100.00%	0.00%

Table 16. Verification of Dispatcher Strategy Parameter

DISPATCHER ATTENTION ALLOCATION STRATEGY	UTILIZATION STATISTICS					
FIRST-IN, FIRST-OUT	Software	average	max average	min average	max	min
	SHADO	26.74%	36.93%	17.97%	100%	0.00%
	Arena	26.42%	40.26%	14.60%	100%	0.00%
PRIORITY	Software	average	max average	min average	max	min
	SHADO	26.41%	38.92%	16.93%	100%	0.00%
	Arena	26.47%	37.59%	17.02%	100%	0.00%
SHORTEST TASK FIRST	Software	average	max average	min average	max	min
	SHADO	26.05%	36.05%	16.10%	100%	0.00%
	Arena	26.47%	36.70%	17.02%	100%	0.00%

Table 17. Verification of Extreme Conditions Parameter

EXTREME CONDITIONS	UTILIZATION STATISTICS					
NONE	Software	average	max average	min average	max	min
	SHADO	26.74%	40.26%	15.87%	100%	0.00%
	Arena	26.42%	40.09%	14.60%	100%	0.00%
TRAIN DERAILMENT	Software	average	max average	min average	max	min
	SHADO	29.00%	43.56%	19.39%	100%	0.00%
	Arena	32.20%	60.50%	15.94%	100%	0.00%
POOR WEATHER	Software	average	max average	min average	max	min
	SHADO	29.20%	39.74%	18.51%	100%	0.00%
	Arena	29.12%	40.16%	16.08%	100%	0.00%
TRAIN DERAILMENT AND POOR WEATHER	Software	average	max average	min average	max	min
	SHADO	30.85	52.32%	20.29%	100%	0.00%
	Arena	35.46%	65.96%	17.67%	100%	0.00%

The researchers reported average utilization computed over 500 days. The max average represents the results of the one day with the highest average utilization across all the 10-minute intervals within that shift; the max represents the maximum utilization value for any one 10-minute interval across all days. SHADO and Arena results generally agreed, with the maximum percentage of disagreement occurring from the Extreme Conditions internal parameter of both types of exogenous events (Type 1 could be a train derailment that introduces a new task; Type 2 could be poor weather that increases times on all related tasks). In that case, SHADO had ~3 percent higher minimum average utilization, ~13 percent lower maximum average utilization, and ~5 percent lower overall average utilization compared to Arena. Yet SHADO and Arena reported the same overall minimum and maximum utilizations at 0 percent and 100 percent, respectively.

Appendix B.
Tables of Time Parameters for RGPC Dispatchers

Table 18. Default Task Timing Input Parameters for Freight Desk per Shift

Dispatcher Task Types	Interarrival Time (minutes)			Service Time (minutes)		
	AM	PM	ON	AM	PM	ON
Actuation (OK)	Expo(16.6)	Logn (43.1,57.6)	Tria(3,5,168)	Unif(2.8,4)		
Actuation (Clear)	Logn (25.9,49.1)	Logn(23.8,43.9)	Tria(2,16,234)	Unif(1.1,2.3)		
Daily Operating Bulletin		Expo(360)			Expo(15)	
Temporary Bulletin Issue	Expo(240)		Expo(1440)	Unif(1.3,4)		
Temporary Bulletin Void & Verify			300			Expo(30)
Other Communications	Expo(17.4)		Expo(60)	Expo(3.4)		
Weather Recording	300		200	Expo(2.5)		
Notetaking	Expo(60)			Expo(1)		
Reporting	Expo(480)			Expo(10)		
Miscellaneous	Expo(60)			Expo(1)		
Transfer-of-Duty	First and Last Task of Shifts			Unif(5,15)		

Table 19. Default Task Timing Input Parameters for Commuter Desk per Shift

Dispatcher Task Types	Interarrival Time (minutes)			Service Time (minutes)		
	AM	PM	ON	AM	PM	ON
Train Movement	Expo(8.1)	Expo(6.8)	Expo(26.7)[1]	Expo(1.7)		
Bulletins	Expo(120)	Expo(240)		Expo(5)		
Temporary Bulletins	Tria(240,480,1440)			Expo(5)		
Bulletin Printing		Expo(450)		Expo(15)		
Other Communications	Expo(60)			Expo(2.8)		
Weather Recording	300		200	Expo(2.5)		
Notetaking	Expo(60)			Expo(1)		
Reporting	Expo(480)			Expo(10)		
Miscellaneous	Expo(60)			Expo(5)		
Transfer-of-Duty	First and Last Task of Shifts			Expo(5)		

[1] The commuter railroad has low traffic in the first 6 hours and high traffic in last 2 hours of the overnight shift.

Appendix C.
Blank Track Warrant Form

RailComm® DOC®

Track Warrant

Number: ____________________ Date: ____________________

To: ____________________ At: ____________________

1. ☐ Track Warrant Number ____________________ is void.
2. ☐ Proceed from ____________ to ____________ on ____________ track.
4. ☐ Work between ____________ and ____________ on ____________ track.
8. ☐ Hold main track at last named point.
9. ☐ Do not foul limits ahead of ____________ ____________ ____________ .
10. ☐ Clear main track at last named point.
11. ☐ Between ____________ and ____________ make all movements at restricted speed. Limits are occupied by train.
12. ☐ Between ____________ and ____________ make all movements at restricted speed. Limits are occupied by:

    ____________ ____________ ____________ ____________ ____________
13. ☐ Between/At ____________ and ____________ do not exceed ______ MPH.

    Between/At ____________ and ____________ do not exceed ______ MPH.

    Between/At ____________ and ____________ do not exceed ______ MPH.
16. ☐ Track bulletins in effect ______, ______, ______, ______, ______, ______, ______, ______.
17. ☐ Other specific instructions:

    ____
19. ☐ Expect to find the following switches lined and locked in the reverse position

    ______, ______, ______, ______, ______, ______.
20. ☐ The following switches may be left lined and locked in the reverse position

    ______, ______, ______, ______, ______, ______.

This Track Warrant has ______ boxes marked.

____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____.

OK: ____________ (time) Dispatcher: ____________ Copied By: ____________

Relayed To: ____________ Acknowledged By: ____________

Limits reported clear at: ____________ (time) Cleared By: ____________

Figure 15. Dispatcher Form to Record Times of Actuation OK and Clear Tasks

Appendix D.
Tables of Human Error Probabilities for RGPC Dispatcher Tasks

Table 20. Human Error Probabilities per Freight Dispatcher Task Type

Freight Dispatcher Task Types	Generic Task Type Description	Triangular Probability Distribution		
		Minimum	Mode	Maximum
Actuation (OK)	Completely familiar, well designed, highly practiced task which is routine	.008%	.04%	.7%
Actuation (Clear)				
Daily Operating Bulletin	Restore or shift a system to original or new state, following procedures with some checking	.08%	.3%	.7%
Temporary Bulletin Issue	Identification of situation requiring interpretation of alarm/indication patterns;	2%	7%	17%
Temporary Bulletin Void & Verify	Restore or shift a system to original or new state, following procedures with some checking	.08%	.3%	.7%
Other Communications	Simple response to a dedicated alarm and execution of actions covered in procedures	.008%	.04%	.7%
Weather Recording	Fairly simple task performed rapidly or given insufficient or inadequate attention	6%	9%	13%
Notetaking	Skill-based tasks when there is some opportunity for confusion	.2%	.3%	.4%
Reporting	Fairly simple task performed rapidly or given insufficient or inadequate attention	6%	9%	13%
Miscellaneous				
Transfer-of-Duty	Skill-based tasks when there is some opportunity for confusion	.2%	.3%	.4%

Table 21. Human Error Probabilities per Commuter Dispatcher Task Type

Commuter Dispatcher Task Types	Generic Task Type Description	Triangular Probability Distribution		
		Minimum	Mode	Maximum
Train Movement	Completely familiar, well designed, highly practiced task which is routine	.008%	.04%	.7%
Bulletins	Restore or shift a system to original or new state, following procedures with some checking	.08%	.3%	.7%
Temporary Bulletin Issue	Identification of situation requiring interpretation of alarm/indication patterns;	2%	7%	17%
Other Communications	Simple response to a dedicated alarm and execution of actions covered in procedures	.008%	.04%	.7%
Weather Recording	Fairly simple task performed rapidly or given insufficient or inadequate attention	6%	9%	13%
Reporting	Skill-based tasks when there is some opportunity for confusion	.2%	.3%	.4%
Bulletin Printing	Fairly simple task performed rapidly or given insufficient or inadequate attention	6%	9%	13%
Miscellaneous				
Transfer-of-Duty	Skill-based tasks when there is some opportunity for confusion	.2%	.3%	.4%

Appendix E.
Talk-and-Listen Time Tables from RGPC Freight Dispatcher Desk

Table 22. Talk-and-Listen Time Data per Shift on March 14, 2018

March14S0	March14S1	March14S2	March14S3
Grand Total 0:52:02	Grand Total 3:22:10	Grand Total 1:38:19	Grand Total 0:08:47
12:00 AM - 1:00 AM 0:14:29	6:00 AM - 7:00 AM 0:12:27	2:00 PM - 3:00 PM 0:25:20	10:00 PM - 11:00 PM 0:02:48
1:00 AM - 2:00 AM 0:11:03	7:00 AM - 8:00 AM 0:36:43	3:00 PM - 4:00 PM 0:18:33	11:00 PM - 12:00 AM 0:05:59
2:00 AM - 3:00 AM 0:05:52	8:00 AM - 9:00 AM 0:41:34	4:00 PM - 5:00 PM 0:06:29	
3:00 AM - 4:00 AM 0:02:13	9:00 AM - 10:00 AM 0:33:05	5:00 PM - 6:00 PM 0:11:57	
4:00 AM - 5:00 AM 0:04:55	10:00 AM - 11:00 AM 0:12:39	6:00 PM - 7:00 PM 0:09:44	
5:00 AM - 6:00 AM 0:13:30	11:00 AM - 12:00 PM 0:38:39	7:00 PM - 8:00 PM 0:11:06	
	12:00 PM - 1:00 PM 0:16:10	8:00 PM - 9:00 PM 0:04:34	
	1:00 PM - 2:00 PM 0:10:53	9:00 PM - 10:00 PM 0:10:36	

Table 23. Talk-and-Listen Time Data per Shift on March 16, 2018

March16S0	March16S1	March16S2	March16S3
Grand Total 0:19:57	Grand Total 3:34:06	Grand Total 1:28:53	Grand Total 0:02:17
12:00 AM - 1:00 AM 0:02:35	6:00 AM - 7:00 AM 0:08:50	2:00 PM - 3:00 PM 0:24:24	10:00 PM - 11:00 PM 0:02:04
1:00 AM - 2:00 AM 0:02:39	7:00 AM - 8:00 AM 0:32:56	3:00 PM - 4:00 PM 0:20:09	11:00 PM - 12:00 AM 0:00:13
2:00 AM - 3:00 AM 0:03:07	8:00 AM - 9:00 AM 0:30:54	4:00 PM - 5:00 PM 0:08:46	
3:00 AM - 4:00 AM 0:00:00	9:00 AM - 10:00 AM 0:59:13	5:00 PM - 6:00 PM 0:09:54	
4:00 AM - 5:00 AM 0:01:49	10:00 AM - 11:00 AM 0:15:26	6:00 PM - 7:00 PM 0:06:27	
5:00 AM - 6:00 AM 0:09:47	11:00 AM - 12:00 PM 0:24:04	7:00 PM - 8:00 PM 0:15:15	
	12:00 PM - 1:00 PM 0:18:02	8:00 PM - 9:00 PM 0:03:58	
	1:00 PM - 2:00 PM 0:24:41	9:00 PM - 10:00 PM 0:00:00	

Table 24. Talk-and-Listen Time Data per Shift on March 17, 2018

March17S0	March17S1	March17S2	March17S3
Grand Total 0:16:20	Grand Total 1:15:13	Grand Total 1:16:37	Grand Total 0:03:16
12:00 AM - 1:00 AM 0:00:20	6:00 AM - 7:00 AM 0:23:18	2:00 PM - 3:00 PM 0:10:08	10:00 PM - 11:00 PM 0:03:16
1:00 AM - 2:00 AM 0:09:35	7:00 AM - 8:00 AM 0:10:36	3:00 PM - 4:00 PM 0:14:44	11:00 PM - 12:00 AM 0:00:00
2:00 AM - 3:00 AM 0:00:00	8:00 AM - 9:00 AM 0:14:09	4:00 PM - 5:00 PM 0:11:44	
3:00 AM - 4:00 AM 0:03:29	9:00 AM - 10:00 AM 0:09:23	5:00 PM - 6:00 PM 0:03:50	
4:00 AM - 5:00 AM 0:00:46	10:00 AM - 11:00 AM 0:05:27	6:00 PM - 7:00 PM 0:01:21	
5:00 AM - 6:00 AM 0:02:10	11:00 AM - 12:00 PM 0:00:48	7:00 PM - 8:00 PM 0:10:14	
	12:00 PM - 1:00 PM 0:08:34	8:00 PM - 9:00 PM 0:14:41	
	1:00 PM - 2:00 PM 0:02:58	9:00 PM - 10:00 PM 0:09:55	

Table 25. Talk-and-Listen Time Data per Shift on May 16, 2018

May16S0	May16S1	May16S2	May16S3
Grand Total 0:48:00	Grand Total 3:36:50	Grand Total 2:44:27	Grand Total 0:10:27
12:00 AM - 1:00 AM 0:01:27	6:00 AM - 7:00 AM 0:20:06	2:00 PM - 3:00 PM 0:17:45	10:00 PM - 11:00 PM 0:04:44
1:00 AM - 2:00 AM 0:04:51	7:00 AM - 8:00 AM 0:41:31	3:00 PM - 4:00 PM 0:31:40	11:00 PM - 12:00 AM 0:05:43
2:00 AM - 3:00 AM 0:04:44	8:00 AM - 9:00 AM 0:41:11	4:00 PM - 5:00 PM 0:27:49	
3:00 AM - 4:00 AM 0:04:03	9:00 AM - 10:00 AM 0:38:22	5:00 PM - 6:00 PM 0:13:31	
4:00 AM - 5:00 AM 0:11:06	10:00 AM - 11:00 AM 0:21:26	6:00 PM - 7:00 PM 0:25:07	
5:00 AM - 6:00 AM 0:21:49	11:00 AM - 12:00 PM 0:21:07	7:00 PM - 8:00 PM 0:25:36	
	12:00 PM - 1:00 PM 0:21:59	8:00 PM - 9:00 PM 0:11:16	
	1:00 PM - 2:00 PM 0:11:08	9:00 PM - 10:00 PM 0:11:43	

Table 26. Talk-and-Listen Time Data per Shift on May 18, 2018

May18S0	May18S1	May18S2	May18S3
Grand Total 0:36:22	Grand Total 3:15:12	Grand Total 2:25:25	Grand Total 0:19:26
12:00 AM - 1:00 AM 0:00:00	6:00 AM - 7:00 AM 0:18:49	2:00 PM - 3:00 PM 0:27:53	10:00 PM - 11:00 PM 0:09:58
1:00 AM - 2:00 AM 0:05:40	7:00 AM - 8:00 AM 0:33:49	3:00 PM - 4:00 PM 0:27:39	11:00 PM - 12:00 AM 0:09:28
2:00 AM - 3:00 AM 0:09:38	8:00 AM - 9:00 AM 0:23:59	4:00 PM - 5:00 PM 0:18:19	
3:00 AM - 4:00 AM 0:01:51	9:00 AM - 10:00 AM 0:33:17	5:00 PM - 6:00 PM 0:19:22	
4:00 AM - 5:00 AM 0:00:30	10:00 AM - 11:00 AM 0:09:59	6:00 PM - 7:00 PM 0:14:25	
5:00 AM - 6:00 AM 0:18:43	11:00 AM - 12:00 PM 0:20:35	7:00 PM - 8:00 PM 0:18:30	
	12:00 PM - 1:00 PM 0:31:55	8:00 PM - 9:00 PM 0:14:11	
	1:00 PM - 2:00 PM 0:22:49	9:00 PM - 10:00 PM 0:05:06	

Table 27. Talk-and-Listen Time Data per Shift on May 20, 2018

May20S0	May20S1	May20S2	May20S3
Grand Total 0:28:41	Grand Total 1:02:36	Grand Total 0:47:04	Grand Total 0:07:01
12:00 AM - 1:00 AM 0:00:00	6:00 AM - 7:00 AM 0:05:11	2:00 PM - 3:00 PM 0:05:30	10:00 PM - 11:00 PM 0:00:00
1:00 AM - 2:00 AM 0:05:07	7:00 AM - 8:00 AM 0:02:43	3:00 PM - 4:00 PM 0:07:05	11:00 PM - 12:00 AM 0:07:01
2:00 AM - 3:00 AM 0:00:00	8:00 AM - 9:00 AM 0:19:26	4:00 PM - 5:00 PM 0:01:37	
3:00 AM - 4:00 AM 0:06:31	9:00 AM - 10:00 AM 0:06:40	5:00 PM - 6:00 PM 0:06:48	
4:00 AM - 5:00 AM 0:07:29	10:00 AM - 11:00 AM 0:10:05	6:00 PM - 7:00 PM 0:07:08	
5:00 AM - 6:00 AM 0:09:34	11:00 AM - 12:00 PM 0:09:33	7:00 PM - 8:00 PM 0:04:52	
	12:00 PM - 1:00 PM 0:07:07	8:00 PM - 9:00 PM 0:08:39	
	1:00 PM - 2:00 PM 0:01:51	9:00 PM - 10:00 PM 0:05:25	

Appendix F.
SHADO Results of Freight Dispatcher Talk-and-Listen Utilization

Table 28. Hourly Freight Dispatcher Utilization per Shift of Default Talk

	AM	PM	ON
Hour 1	63.41%	56.27%	24.69%
Hour 2	16.96%	21.63%	0.00%
Hour 3	6.25%	2.08%	0.00%
Hour 4	42.93%	23.75%	3.54%
Hour 5	61.02%	30.57%	3.82%
Hour 6	15.01%	38.01%	23.98%
Hour 7	14.85%	6.36%	0.00%
Hour 8	82.69%	36.79%	23.66%
Hour 1	53.28%	39.38%	21.77%
Hour 2	43.68%	26.61%	4.80%
Hour 3	34.88%	46.56%	0.00%
Hour 4	8.84%	32.07%	0.00%
Hour 5	22.97%	2.51%	0.54%
Hour 6	16.46%	4.11%	24.32%
Hour 7	21.73%	45.66%	9.41%
Hour 8	51.03%	24.98%	18.20%
Hour 1	70.06%	70.65%	25.21%
Hour 2	12.89%	38.72%	2.06%
Hour 3	10.48%	4.52%	0.00%
Hour 4	29.35%	20.52%	1.92%
Hour 5	5.93%	25.27%	0.00%
Hour 6	23.38%	30.18%	1.90%
Hour 7	20.91%	2.40%	0.00%
Hour 8	27.34%	22.83%	22.22%

	AM	PM	ON
Hour 1	58.01%	54.32%	38.91%
Hour 2	4.93%	4.79%	15.37%
Hour 3	9.69%	16.14%	4.00%
Hour 4	0.00%	11.44%	0.03%
Hour 5	17.41%	3.44%	5.81%
Hour 6	13.21%	28.93%	6.24%
Hour 7	43.55%	5.31%	9.48%
Hour 8	35.23%	23.39%	27.93%
Hour 1	98.29%	47.42%	21.77%
Hour 2	13.07%	4.84%	1.96%
Hour 3	7.46%	13.20%	0.00%
Hour 4	18.63%	6.68%	6.59%
Hour 5	39.21%	12.07%	2.95%
Hour 6	19.87%	12.31%	2.74%
Hour 7	34.76%	18.88%	24.35%
Hour 8	37.82%	31.96%	42.02%
Hour 1	68.00%	42.61%	25.18%
Hour 2	35.71%	32.28%	2.11%
Hour 3	6.68%	12.06%	8.30%
Hour 4	22.90%	3.99%	0.31%
Hour 5	14.04%	19.58%	9.40%
Hour 6	39.33%	32.57%	0.39%
Hour 7	27.60%	9.01%	14.65%
Hour 8	78.23%	35.89%	29.41%

Appendix G.
Adjusted Input Parameters for What-If Scenario 5.1

Sharples et al. (2010) shared a summary of distribution of observed behaviors of dispatchers (better known as "signalers" in the UK) for non-automatic and automatic VDU systems with mean and S.D. percentage for each related task. The percent changes from conventional to automatic were used to adjust the mean service time parameters (Table 29).

Table 29. Service Times Validated and from Observational Study (Sharples et al., 2010)

Dispatcher Task Types	**Default Mean (minutes)**	*Observed Conventional Relative Mean*	*Observed Automatic Relative Mean*	*Observed Conventional Relative Max*	*Observed Automatic Relative Min*	*Observed Conventional Relative Min*	*Observed Automatic Relative Max*
Train Movement	1.7	*11.57%*	*7.50%*	*16.67%*	*3.28%*	*6.47%*	*11.72%*
Bulletins	5	*8.33%*	*11.14%*	*14.47%*	*5.00%*	*2.19%*	*17.28%*
Temporary Bulletins	5	*8.33%*	*11.14%*	*14.47%*	*5.00%*	*2.19%*	*17.28%*
Bulletin Printing	15	*1.57%*	*0.58%*	*3.99%*	*0.00%*	*0.00%*	*1.68%*
Other Communications	2.8	*5.34%*	*7.78%*	*9.72%*	*4.09%*	*0.96%*	*11.47%*
Weather Recording	2.5	*1.57%*	*0.58%*	*3.99%*	*0.00%*	*0.00%*	*1.68%*
Notetaking	1	*11.78%*	*9.04%*	*16.91%*	*4.57%*	*6.65%*	*13.51%*
Reporting	10	*1.57%*	*0.58%*	*3.99%*	*0.00%*	*0.00%*	*1.68%*
Miscellaneous	5	*4.38%*	*22.38%*	*9.71%*	*4.38%*	*0.00%*	*40.38%*
Transfer-of-Duty	5	*1.46%*	*2.08%*	*2.95%*	*0.00%*	*0.00%*	*4.47%*

Appendix H.
What-If Scenario 5.1 Results

Table 30. Default versus Mode Automated Commuter Dispatcher Utilization

	Commuter AM	Commuter PM	Commuter ON	Mode Auto Commuter AM	Mode Auto Commuter PM	Mode Auto Commuter ON
Average	46.82%	51.95%	27.20%	66.24%	66.15%	53.95%
Standard Deviation	6.98%	8.16%	6.56%	15.82%	15.73%	17.49%
Min Average	29.44%	30.99%	12.20%	29.10%	31.13%	14.25%
Max Average	66.24%	74.25%	49.09%	100.00%	100.00%	99.13%

Table 31. Worst versus Best Automated Commuter Dispatcher Utilization

	Worst Auto AM	Worst Auto PM	Worst Auto ON	Best Auto AM	Best Auto PM	Best Auto ON
Average	79.04%	78.93%	67.00%	55.26%	57.56%	46.84%
Standard Deviation	14.17%	13.15%	16.76%	14.74%	15.59%	14.52%
Min Average	38.90%	38.17%	27.86%	17.55%	24.92%	80.86%
Max Average	100.00%	100.00%	99.51%	98.15%	98.38%	15.83%

Abbreviations and Acronyms

ACRONYM	**DEFINITON**
CFR	Code of Federal Regulations
CTC	Centralized Traffic Control
DES	Discrete Event Simulation
FMCSA	Federal Motor Carrier Safety Administration
GE	General Electric (GE Global Research Center)
MOW	Maintenance-of-Way
OEM	Original Equipment Manufacturer
ON	Overnight
PTC	Positive Train Control
QNS&L	Quebec North Shore & Labrador Railway
RGPC	Rio Grande Pacific Company
RSIA	Rail Safety Improvement Act
RTC	Rail Traffic Controller
SHADO	Simulator of Humans & Automation in Dispatch Operations
SME	Subject Matter Expert
T&LT	Talk-and-Listen Time
TWC	Track Warrant Control
UK	United Kingdom
UTU	United Transportation Union
VDU	Visual Display Unit