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Concepts of Operations for Autonomous Vehicle Dispatch Operations

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Abstract

The future of surface transportation will likely include fleets of autonomous vehicles (AVs), both passenger and freight. Such futuristic operations will require remote monitoring of individual and fleets of AVs through an operations center staffed by personnel that resemble present-day surface transportation dispatchers. This report outlines three new functionalities unique to AV dispatchers as well as five broad Concepts of Operation (CONOPs) that illustrate how such AV remote management could develop, including Original Equipment Manufacturing (OEM) AV Dispatch Support, Robo-Taxi Dispatch, Autonomous Trucking Dispatch, Public Transportation AV Dispatch, and State/Regional AV Management and Dispatch. To further understand implications of AV dispatch tasking on dispatcher workload, a case study was developed that examined how AVs could impact a regional dispatch center. A dispatcher workload discrete event simulation yielded several models that examined both single and two-person dispatcher models under both typical and emergency operations. These models indicate that even with minimal new tasking caused by the arrival of AVs, the additional workload would likely overload a single dispatcher, even under a normal operational tempo, requiring additional personnel. Results also suggest that in order to ensure dispatchers are not bored and distracted, dispatchers may need to share tasks instead of specializing across tasks. Understanding that these results are only specific to this case study, this study demonstrates why companies and agencies anticipating the integration of AVs in their transportation networks need to build such models in order to determine how to safely develop and staff futuristic AV dispatch centers.

Introduction

While there is significant debate about when autonomous vehicles, aka self-driving or driverless cars, will become part of the driving landscape, there is general agreement that they will eventually be introduced across the country in various operational driving domains. As fleets of such vehicles move into operations and reliable vehicle-to-vehicle (V-to-V) and vehicle-to-infrastructure (V-to-I) networks are established, there will be an increasing need for remote supervision of such vehicles by humans to ensure safe operation in contingency and emergent situations.

One recent example occurred in Southern California during the Thomas Fire, when many mobile navigation apps advised their users to follow roads that were closed due to imminent fire hazards. This occurred because the crowdsourced apps automatically identified them as having little traffic. This problem resulted in the Los Angeles police warning drivers against using mobile navigation in these areas to prevent them from driving directly into the fire (Felton, 2017). Developers had to quickly intervene to stop the apps from making the dangerous recommendations. Such problems will become even more critical for autonomous vehicles (AVs) without drivers who provide understanding of local context, so the role of external dispatchers will likely become even more critical as the technology matures.

While remote operations centers exist for several modes of transportation, such as air traffic control, flight dispatch, rail dispatch, and public safety for police, ambulance and state vehicles, limited attention has been given to the design of remote operations centers for AVs. Thus, there is a need to develop various Concepts of Operations (CONOPs) to begin understanding how AVs will affect the future of surface transportation dispatch.

The purpose of a CONOPs is to describe the operational needs and systems characteristics for a proposed system (e.g., expected uses, user requirements, and relationships to existing systems). CONOPs typically include a description of relevant characteristics of current systems and environments, descriptions of a proposed new system, and scenarios illustrating use of the new system in real-world environments, which address both internal and external factors (MITRE 2014).

This effort will describe various CONOPs that address how dispatch operations for traditional and autonomous vehicles could evolve in both public and private settings. Five different concepts of operations are explored, with a focus on the CONOPs for a regional public safety dispatch center, including how the insertion of AV tasking would likely change staffing models.

1. Defining Autonomous Vehicles

In order to understand how autonomous vehicle dispatch operations are likely to evolve, it is important to first define autonomous vehicles and clarify terminology relating to these vehicles. For the purposes of this report, autonomous vehicles are any form of motorized vehicles containing sensors and algorithms that allow the vehicles to move from one location to another with no need for any human driver input. Thus, cars, trucks, and even motorcycles would fall under this definition if they could all be commanded to go from point A to B autonomously, and were able to execute such a command relying only on their internal sensors and algorithms. In such settings, passengers may or may not be present, as in the case of autonomous trucks or small grocery delivery vehicles.

In order to understand the various possible dispatch CONOPs that could emerge given this definition of autonomous vehicles, it is important to first understand the Society of Automotive Engineers (SAE) levels of automation. The SAE has detailed a framework to describe the different levels of automation that could occur for various instantiations of autonomous vehicles (Table 1). These levels have been widely adopted across industry and government, most notably the National Highway Traffic Safety Administration (NHTSA), as seen in Table 1 (the SAE's illustration of SAEJ3016).

For the purposes of this report, the assumption is that dispatch centers will be needed to supervise Level 4 and 5 vehicles, as per Table 1. In Level 4, vehicles can drive themselves in various operational domains, perhaps like on interstates, but humans can take over as desired or required. In Level 5 operations,

Table 1: Levels of automation in self-driving and driverless cars, as set forth by SAEJ3016

SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System capability (driving modes)	BASt Level	NTHSA Level
Human Driver monitors the driving environment								
0	No Automation	the full-time performance by *the human driver* of all aspects of the *dynamic driving task*	Human Driver	Human Driver	Human Driver	N/A	Driver only	0
1	Driver Assistance	the *driving mode-specific* execution by a driver assistance system of either steering or acceleration/deceleration	Human Driver and Systems	Human Driver	Human Driver	Some Driving Modes	Assisted	1
2	Partial Automation	Part-time or driving mode-dependent execution by **one or more driver assistance systems** of both steering and acceleration/deceleration. Human driver performs all other aspects of the *dynamic driving task*	**System**	Human Driver	Human Driver	Some Driving Modes	Partially Automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	*driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* - *human driver* **does** respond appropriately to a *request to intervene*	System	**System**	Human Driver	Some Driving Modes	Highly Automated	3
4	High Automation	*driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* - *human driver* **does not** respond appropriately to a *request to intervene*	System	System	**System**	Some Driving Modes	Fully Automated	3/4
5	Full Automation	**full-time** performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	**System**	Some Driving Modes		

humans can never take over as there are no controls to do so. The distinction in this report between self-driving cars and driverless cars will be equivalent to the distinction between Levels 4 and 5 in Table 1.

2. Current US Dispatch Operations

Dispatchers in surface transportation settings are primarily responsible for coordinating activity across a network with an emphasis on promoting both efficiency and safety. Dispatchers are found in all segments of transportation including aviation (Nneji, Cummings et al. 2018), rail (Roth, Malsch et al. 2001), and even in maritime communities (Li, Wu et al. 2015). In surface transportation, they are typically found in freight management, such as dispatchers for fleets of commercial delivery trucks, but also in commercial passenger operations like taxis and in first-response settings for ambulance, 911, fire, and police operations.

For example, in the trucking industry dispatchers coordinate delivery schedules, communicate with both truckers and customers in the event of delays or other contingencies, and keep drivers apprised of any significant routing issues. Ambulance and first response dispatchers also perform similar tasks, but in these settings, operations are event-driven and usually high priority, often requiring the dispatcher to communicate with various government agencies and hospitals, as well as the public (Weiner and Solorio 1990). These two examples highlight the fact that not all dispatchers face the same task demands.

There are two general types of dispatchers, those that work in private/commercial settings like dispatchers in freight movement and those that work in support of public safety, such as ambulance dispatchers or road maintenance crews, as depicted in Figure 1. These dispatchers can be further categorized by the temporal nature of their work, in terms of whether operations are generally planned in advance versus unplanned. Planned means that a delivery schedule between vehicles and customers is developed hours or days before deliveries are attempted and thus a plan is developed ahead of time. Unplanned operations are those where dispatchers are reacting to emergent events that cannot be precisely known in advance, like when an accident is going to happen or when a person might need a cab.

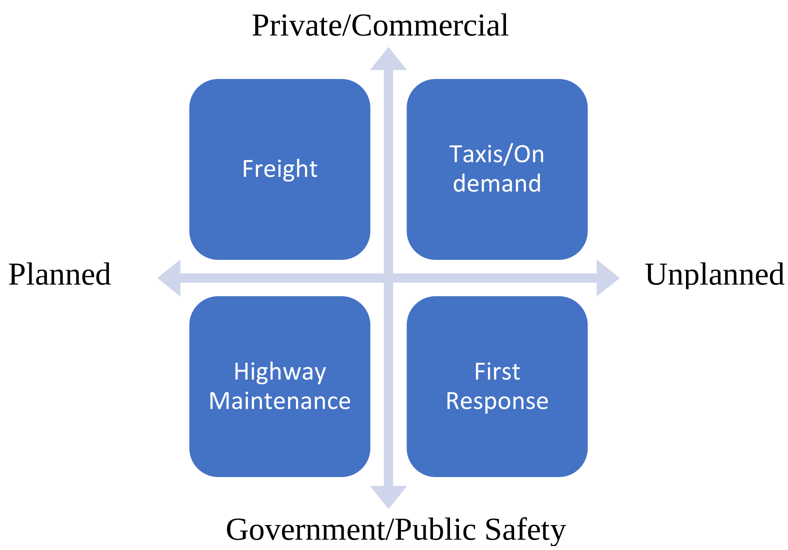

Figure 1: Examples of Different Classifications of Transportation Dispatchers

Understanding the temporal nature of such dispatch operations is critical when considering staffing, i.e., it is much easier for a company like Walmart to schedule their dispatchers since their trucks have regular routines and schedules can be optimized prior to the day of execution. Unplanned events are harder to anticipate, and so dispatchers in these settings face greater variability in tasking and response times.

Dispatchers of unplanned systems can predict what a typical day might look like in the case of passenger or police-response demand, but uncertainty is much higher in these systems and thus, dispatchers can experience significantly greater highs and lows in demand.

One new source of uncertainty for public safety dispatchers has been the increased need to interface with mapping app companies like Waze and Google maps. While such services are meant to provide expedited automated navigation assistance to drivers, in cases of emergencies like the arrival of a hurricane, the app-based mapping services may not understand the context of emerging events, creating significant problems. In 2018, state dispatchers in North Carolina had to intervene directly with such services to have them update the apps and direct people away from the coast as a hurricane arrived (O'Brien 2018). Thus, uncertainty can come from unexpected sources and add significantly to the workload of dispatchers of unplanned systems.

The boundaries in Figure 1 are not rigid, i.e., while there may be planned highway maintenance, often dispatchers must respond to emergent scenarios, like when a tree has fallen on a power line, blocking a road. In such a case, a first response dispatcher must coordinate with a maintenance dispatcher to address the problem. Even the division between private and public dispatch roles is not crisp since governments often subcontract out dispatch roles to private companies. That aside, it is important to understand that Figure 1 demonstrates that not only are there different types of dispatchers, but that their intrinsic motivations may be different. Government dispatchers are primarily motivated by preserving public safety while private companies are motivated by profit. Thus, where and how dispatchers focus their efforts and the timeliness of their responses will be dictated by their classification in Figure 1.

Given these different surface transportation dispatching applications, it is worth elucidating a list of general functions that such dispatchers execute, understanding that the specific application, especially in terms of whether the dispatcher is commercial versus government, will drive the exact set of functions to be performed. Moreover, most dispatch operations require multiple people to meet these various functions, depending on the time and area of coverage.

- For most dispatchers, the primary function is one of **communication**, whether it be with customers, drivers, mapping companies, public agencies or support groups such as maintenance personnel. Such communications can occur through radios, phones, text messaging, and e-mails. In addition, especially during shift handovers, there is face-to-face communications with other dispatchers.
- Many dispatchers, regardless of domain, must engage in some form of **resource allocation**, which is matching a need to a response unit, such as which fire trucks can respond to a call or which maintenance vehicle can be assigned to a fallen tree on a highway that needs clearing. In private/commercial settings, dispatchers match vehicles to customer requests, but in unplanned settings, will often attempt to anticipate surges in demand and direct vehicles to go to airports or sports stadiums during busy times.
- Many dispatchers provide high-level **navigation support** for drivers such as notifying a network of trucks of a recent road closure or pending significant weather event, and providing the drivers with alternate routes. For public dispatchers, often these tasks are carried out through the management of overhead message signs on interstates.
- **Contingency management** is another significant element of a dispatcher's responsibilities, regardless of which Figure 1 sector a dispatcher is in. For example, dispatchers working with predetermined schedules have to deal with minor contingencies such as whether a truck is available to pick up another truck's load due to mechanical problems. Even those dispatchers working in safety-critical unscheduled settings like ambulance dispatch have to deal with contingencies above and beyond normal tasking such as responding to a mass casualty event like a shooting.

- All dispatchers constantly **monitor** their schedule and area of oversight for potentially urgent or emergent events. Depending on the setting, some dispatchers monitor audio radio traffic, others monitor cameras such as dispatchers of toll roads, and some monitor both.
- All dispatchers are required to complete logs and other **paperwork** that catalogue their actions.
- Lastly, dispatchers will occasionally engage in **training** either as a trainee or an instructor.

These seven generic functions, also found in other dispatcher transportation settings (Roth, Malsch et al. 2001, Nneji, Cummings et al. 2018), are representative of the functions that dispatchers do today. However, with the arrival of self-driving and/or driverless cars, it is possible that new functions will be introduced for dispatchers across all four settings in Figure 1. While the present-day seven functions will still exist for AV dispatchers of the future in slightly modified ways, the next section will outline new functions that are likely to emerge in such settings.

3. Possible New AV-Related Functions in Dispatch Centers

The introduction of AVs into surface transportation systems, both passenger and freight, will bring many new functions that will need to be incorporated into a dispatch center, regardless of the exact final form. We propose that three new basic functions could be needed in AV supervisory control and monitoring, 1) remote control of AVs, 2) passenger communications and 3) monitoring of platooning vehicles. These are discussed in detail below.

a. Remote Control/Teleoperation

While developers of autonomous vehicles (AVs) have made numerous advances in computer vision and navigation capabilities, computer intelligence still lags well behind human abilities when making decisions in novel situations or in scenarios where sensors are degraded. While automation may be consistent and highly accurate at making rapid responses to known stimuli and does not get distracted or fatigued, often autonomous systems encounter situations that they cannot handle and behave in unpredictable ways. For this reason, systems like AVs that operate in uncertain environments can be expected to require some degree of human oversight for the foreseeable future (Cummings 2019). One alternative for resolving these problems is through remote operation (Sheridan 1992).

Several companies are already investigating remote operation of autonomous vehicles. Zoox and Toyota have US patents for controlling AVs remotely (Okumura & Prokhorov, 2014; Levinson, et al., 2015), but few details on their actual use have been provided. Nissan has suggested that they are working on a dispatch center that will have humans ready to teleoperate AVs whenever a car cannot adapt to changes in the environment (Davies 2018). This system, called *Seamless Autonomous Mobility* (SAM; Nissan, 2017), is a call center with human operators available to remotely take control of an autonomous vehicle stuck in a situation it is unable to resolve. In a demonstration, the autonomous vehicle would call SAM if it encountered a problem. A human operator would then remotely provide a new path for the vehicle and return control. These different visions of remote control highlight that there are important nuances in understanding how remote control of an AV *could* and *should* evolve. The next sections discuss when and where teleoperation vs. goal-based supervisory control will likely be implemented.

<u>*Teleoperation*</u>

There are some developers who believe that the answer to potential AV confusion is to provide a remote replica of car controls, complete with steering wheel and screens that capture camera input from the remote vehicle, e.g., (Dickey 2018). In this model, remote drivers literally take over full control, including steering and speed and brake control.

While such a capability may seem to provide a temporary solution in allowing a human driver to remotely operate an AV when it can no longer function in its operational domain, there are critical issues that raise concern about the viability of such an approach. First, it is not clear what communication lags will exist in such control networks. There is a well-known human-induced latency called the neuromuscular lag, which means that humans cannot reliably respond to incoming information less than 200-500ms (Card, Moran et al. 1983, Jagacinski and Flach 2003). Thus, any remote driver cannot be expected to correctly respond to external stimuli that requires a response in less than that time. Any CONOPs that requires any remote operator to take control of a vehicle on the scale of seconds would be extremely unsafe, especially at highway speeds.

Figure 2: Example of Remote AV Teleoperation, Photo Credit: Phantom Auto (Dickey 2018)

There is also an inherent cognitive switching cost when automation alerts a human to take over, and research has demonstrated that such handovers can lead to significant delay due to human driver reorientation to the task (Morgan, Alford et al. 2016). Moreover, these response times are further complicated by issues of attention, vigilance, and boredom of the dispatcher, and so a response time of around a half second is only possible if the remote driver is perfectly paying attention. There have been a significant number of vigilance problems of remote supervisors attending to unmanned systems (Cummings and Gao 2016), and it is likely that dispatchers of AVs will also suffer from similar problems.

Such delays in human response will be exacerbated by any delays in communication networks, as well as any delays in AV decision-making. The Uber crash in 2018 that resulted in the death of a pedestrian demonstrated a significant delay in the computer deciding whether a pedestrian was present (Griggs and Wakabayashi 2018). Thus, the combination of human plus AV plus possible network delays could result in catastrophe, particularly at high speeds. Given these physical and cognitive limitations, the most likely safe use of remote drivers would be for very slow speed operations (less than 10mph) and in cases like pulling a car to the shoulder, slowly reversing, and clearing the AV from unsafe circumstances.

Goal-based Supervisory Control

In addition to teleoperation, which occurs when a person remotely directly commands heading and speed of the car as discussed above, there is another option where the remote dispatcher engages in goal-based supervisory control. In such a paradigm, an operator monitors a situation, such as when an AV senses a critical camera has failed and stops on a highway. Instead of engaging a throttle and steering the car, a goal-based supervisor will give a command to the vehicle, such as pull forward 5 feet and move laterally 10 feet to the right at 5mph. Instead of directly controlling the vehicle, the remote supervisor gives the vehicle goals, and then the vehicle executes these goals.

Such a control architecture is superior to teleoperation as it is time invariant, meaning that delays in communication have no effect on the ability to carry out the task. Goal-based supervisory control typically requires significantly less training as it is effectively a point-and-click task, whereas teleoperation requires significantly more training and practice (Sheridan 1992). The one drawback to such an approach is that flexibility is lost in maneuvering and it may take many intermediate commands to reach a goal. For example, a person teleoperating a car may be able to maneuver a car more quickly that becomes stuck due to a degraded sensor as compared to supervisory control which may take several discrete commands to reposition.

In its current testing in Arizona, Waymo has stated that it is taking a goal-based supervisory approach for remote control through a role called "fleet response." This person, completely separate from the dispatcher who concentrates on fleet scheduling, supervises AVs in difficult scenarios and then updates the fleet with relevant environmental updates, like road closures (Madrigal 2018).

Regardless of which form of remote control is used, teleoperation or goal-based supervisory control, some version of a human dispatcher will be needed to carry out the tasks, which are new functions that dispatchers of today are not required to perform. The primary considerations in adding these functions to the many tasks dispatcher already perform are workload and attention management. Teleoperation requires dedicated attention, and goal-based supervisory control requires intermittent attention. Generally, people performing supervisory control tasks can better timeshare attention across multiple tasks (Cummings, Bruni et al. 2007). In either case, adding a new function of remote control could significantly add to dispatcher workload and so any new CONOPs for dispatchers must make workload a primary measure, in addition to other performance measures.

b. Communications with Passengers

While such forms of emergent control of AVs would likely represent a small fraction of dispatcher responsibilities, there are other types of interventions a dispatcher might encounter. One new function that dispatchers of AVs may need to add to their task list is communicating with passengers. Under current operations, communicating with various entities constitutes a major part of any dispatcher's tasking, but these entities are typically other dispatchers, maintenance crews, mapping companies, etc. Because passengers in Level 5 cars will not understand urgent or emergent situations, like an AV pulling off to the side of the road because a flat is detected, someone in a dispatch center will need to communicate with them.

Indeed, GM is the OEM with the most mature capability in passenger communication as it already has an underlying dispatch infrastructure through its OnStar® subscription-based offering[1], where a dispatcher can assist a driver in a traditional vehicle in the case of an urgent or emergent situation. Presently, drivers call OnStar® when they need aid for minor problems like flat tires and the OnStar® operators, akin to dispatchers, can coordinate roadside services.

In the event of a collision, an OnStar® operator is notified through automated sensors of the vehicle's condition and its GPS location to allow the operator to coordinate first responders as well as communicate with the driver. OnStar® also provides stolen vehicle tracking, hands-free calling, turn-by-turn navigation, and remote diagnostics of a car's systems throughout the US. In times of a natural disaster or severe weather conditions, OnStar®'s Crisis Assist provides drivers with safe alternative routes or general information about the unfolding situation.

As AVs become more commonplace, services like OnStar® will need to adapt to focus on the passengers instead of the drivers and they will likely need to coordinate with other public safety

[1] www.onstar.com

dispatchers. Waymo has already developed such a capability for passengers riding in its experimental driverless car service, these dispatchers fall into the rider support division. Their primary job is to monitor and interface with customers who need help.

c. Fleet Management

Because of the possibility that a dispatcher can communicate with multiple AVs at once, assuming reliable connectivity, managing a fleet of vehicles will be a new function that dispatchers will need to incorporate. Tasks that would fall within this function include ensuring information, such as road closures, is successfully communicated across a fleet of vehicles to ensure their redirection, as well as directing fleets of vehicles to areas of high need or directing fleets away from problem areas, like a bridge collapse. Such a capability where dispatchers could directly influence fleets of connected AVs represents a potentially powerful new application that has never before been possible and could have significant public safety implications. However, one caveat to this important new capability is the requirements for widespread and reliable connectivity between cars and with the remotely-located dispatchers.

Another significant new dispatch issue that will arise with the arrival of AVs is the training cycle that will need to occur with software updates, which can occur quite frequently. Every time a new software update is pushed to a fleet of vehicles, all the dispatchers who oversee both individual and fleets of vehicles will need to receive specific training on what has changed since the previous update. While some updates may be minor, some could be major requiring significantly revised or completely new procedures for dispatchers. Thus, the training requirements for dispatchers of AVs are likely to be more, with more frequent updates than for traditional vehicles.

Platoon Monitoring

One possible fleet management concept of operation for freight AVs at a smaller scale is the concept of platooning of multiple trucks. In platooning operations, a lead truck which has a human driver (who could be operating at a SAE level 2, 3, or 4 (Table 1) truck on the highway), is closely followed by one or more other trucks which may have a driver supervising a level 4 truck, or the truck may be unmanned with no driver in it. The motivation for such close following, also called drafting, is to take advantage of reduced drag and improved fuel efficiency (Automated Driving and Platooning Task Force 2015).

Such close operations would require intense focus of a human driver and would be fatiguing, so such precise position maintenance is far more suited to computers. Because of this increased workload, the driver of such a platoon will need additional support from a remote dispatcher, who would likely monitor the platoon as a micro-fleet, watching the distances and communications between the trucks and also keeping abreast of changing external conditions such as weather and traffic to provide support for the driver of the lead vehicle, as well as any other platooning operations in the area of operation.

4. Representative Concepts of Operations

While there are many ways current commercial and government dispatch operations may be affected by the arrival of autonomous vehicles (AVs), we present the following five possible general concepts of operations that demonstrate how current dispatch operations could change in light of the new functionalities that will be needed. While these are presented as stand-alone CONOPs, they are not mutually exclusive and it is likely that they could be combined in practice.

a. Concept 1: Original Equipment Manufacturing (OEM) AV Dispatch Support

Automotive companies like Ford and GM have invested significant resources in the development of autonomous vehicles through their subsidiaries Argo.ai and Cruise. While it is not yet clear how markets will evolve for these companies, one possible CONOP is that the OEMs like Ford and GM will manage their own fleets of AVs, either privately owned or leased, and thus will need a dispatch center to do so. Other OEM applications could include small autonomous shuttles by companies such as Navya (Figure 3), and this will be discussed more in a later section.

Given that GM's OnStar® centers already provide passenger communications, vehicle navigation updates and status information, and support for a number of urgent and emergent scenarios, much of which is already automated like collision detection, extending such a capability to include the oversight of AVs is a distinct future possibility. These extensions would likely include the ability of a dispatcher to remotely control the vehicle, for example, to move it from a highway to a shoulder in the case of an accident as discussed earlier. Moreover, the current Crisis Assist capability would likely be modified to include fleet management in real time, for example, commanding groups of vehicles at the same time to turn around in the case of a flood. While GM is the only OEM company that currently has an established dispatch network that coordinates trip support and emergency services that could be adapted to AV dispatch services, Nissan has committed to develop AV dispatch capabilities (Nissan 2017).

In addition to attending to basic scheduling tasks, communicating with passengers, and occasionally intervening in single or group vehicle behavior, future AV fleet dispatchers will also need to communicate with regional government dispatchers. This kind of public-private collaboration will be needed in times of crisis to prioritize the safety of the passengers of the car as well as others on the road. Such crisis response could take the form of redirecting cars at both the individual and aggregate level, meaning that entire fleets of AVs could be redirected away from a major crash that has shut down an interstate.

Navya Arma Shuttle, courtesy of Frank Schwichtenberg

b. Concept 2: Robo-Taxi Dispatch

A very popular application of AVs is the concept of Robo-Taxi, which is the idea that through the use of a smart phone-based app, people can call an AV as a commercial service, much like present-day taxi operations. Such a model is often referred to as On-Demand Mobility (ODM) and for such a CONOP, it is likely that a private company, much like Uber or Lyft, will be responsible for both manned and unmanned fleet management. While human-driven taxi companies today typically have their own dispatch centers that manage their fleets to maximize the number of trips with the fewest number of vehicles, ODM companies currently do this through intelligent systems. However, taxi services are increasingly using such computer-based systems with their own intelligent apps (Trego 2018).

With the arrival of AVs as Robo-Taxis that operate as either L4 or L5 (Table 1), any ODM company will need to develop a dispatch center that focuses primarily on monitoring overall fleet health and status and efficiency in scheduling, customer-interfacing communications and intervening in contingency operations, like pulling a car to the road shoulder. Currently, Waymo is the only Robo-Taxi company that has acknowledged the development of such a capability, with a dedicated dispatch center in Phoenix, where they are currently testing their autonomous vehicle operations.

Waymo has elected to split their Robo-Taxi dispatch functions across three different roles, traditional dispatch, fleet response, and rider support (Madrigal 2018). Thus, presumably the scheduling and navigation functions are handled by the dispatcher, remote control and fleet management are handled by the fleet response person, and the rider support person deals with passenger communications. As will be demonstrated in a later section, the size of the fleet under supervision, the number of functions one or more dispatchers are required to perform, and task frequency drive overall optimal staffing numbers and job assignments.

One critical consideration when determining how large a dispatch team needs to be and what functions should be split or shared across a team is how communications will add or detract to performance. The more personnel who are added to such teams will increase the internal communication overhead, which ultimately could affect overall workload and potentially levels of frustration (MacMillan, Entin et al. 2004). Ensuring that workload does not get too high for a team of AV dispatchers, especially under contingency operations, will be a major consideration going forward, and this will be analyzed in more detail in a later section.

c. Concept 3: Autonomous Trucking Dispatch

Given the proposed ability of AVs to operate consistently over long periods of time, the desired use of autonomous vehicle technology in long-haul trucking is not surprising. Fatigue is a significant source of concern for the safe operation of human-driven long-haul operations (Wylie, Shultz et al. 1996) Allowing an autonomous truck (AT) to drive itself long distances would not only remove this fatigue concern, it could also improve efficiency and reduce variability in delivery schedules.

Trucking companies already use dispatchers to track their trucks, interface with customers, and support drivers with schedule and road condition updates, so if and when ATs become commercially viable[2], such operations will likely need to be updated to include supervision of the ATs along with the traditional trucks (TTs). New AT dispatch functions could include the need to remotely control the vehicles when problems emerge and also introduce AT fleet management issues such as identifying when and where ATs would refuel, coordination with the refueling and maintenance teams, and updating the AT fleet with weather, road closure, and other contextual information. In addition, dispatchers would likely monitor hazardous or perishable cargos to ensure proper internal environments.

While it may seem advantageous for companies to adapt an existing trucking dispatch network to include AT dispatchers, it is not yet clear how the mix of TTs and ATs should be handled from the perspective of a dispatcher. For example, should one dispatcher handle a heterogeneous mix of TTs and ATs or should there be two separate types of dispatchers for each technology? Having two different types of dispatchers may seem to be an obvious answer but cost could drive a final dispatch staffing model, as companies may not be able to support two different classes of dispatchers. In addition, previous research has shown that supervisors of autonomous systems that require little interaction cause significant boredom with an increased risk of degraded human performance (Cummings and Gao 2016, Cummings, Mastracchio et al. 2013). However, as discussed previously, workload could be too high, especially during contingency operations, so

[2] Recently an established autonomous trucking company, Starsky Robotics, closed its doors and the CEO made a public statement that such an autonomous vehicle application was not possible in the foreseeable future Seltz-Axmacher, S. (2020). "The End of Starsky Robotics." from https://medium.com/starsky-robotics-blog/the-end-of-starsky-robotics-acb8a6a8a5f5..

how to balance functions, tasks, and number of people is a difficult workforce development problem. A later case study will illustrate these problems.

As discussed in an earlier section, one derivative CONOP that could emerge in AT operations is the concept of platooning, where a human-driven truck leads a caravan of closely-following ATs. The lead driver of such a platoon will need significant dispatcher support since the driver’s eyes need to be on the road, and so the remaining tasks of monitoring each of the following ATs in terms of fuel, engine and tire health, and cargo and communications viability could fall to a dispatcher. The concept of platooning would likely significantly increase the workload of a dispatcher and depending on the complexity of the trip, could be the dispatcher’s only job (which raises questions about the economic viability of such a CONOP).

While dispatchers of ATs do not have the added function of having to communicate with passengers, they will likely experience increased communications with all the various support teams. In addition, given the potentially catastrophic outcomes in the event of an accident with platooning trucks moving at highway speeds, AT dispatchers will likely have to communicate with regional public safety dispatchers who will want to monitor the progress of such high-risk vehicles through their regions. A later CONOP will discuss these regional dispatchers in more detail.

d. Concept 4: Public Transportation AV Dispatch

The three previous CONOPs all focused on private/commercial dispatch needs for both autonomous vehicles and trucks, but there could also be public/government-sponsored applications of such technologies that also require dispatch support. The first of these will focus on public transportation AV dispatch.

Worldwide cities are engaging the automotive industry for public transportation solutions that will reduce emissions, and also reduce operational costs. Given the rise in AV technologies, many enterprising companies have proposed small slow-speed shuttles that are both autonomous and electric as partial solutions. The Navya shuttle in Figure 3 is one such shuttle, and EasyMile, with shuttles at NC State University, is another major competitor with a similar vehicle[3]. These and other companies sponsor multiple test sites around the world, exploring the viability of such shuttles as a form of public transportation. While these shuttles typically do not have a driver, they have an attendant onboard as well as a remotely-connected dispatcher.

Given their experimental nature at this point in time, the dispatch services provided for these shuttles are privately owned and operated, but it is possible that once these shuttles are deemed operational, they could be integrated into public transportation systems by state and local governments. Regardless of whether such shuttles are operated directly by such governments or by sub-contractors, not only will they need to have oversight by dispatchers with unique skill sets for managing the AV shuttles, but for the foreseeable future, they will have to integrate these services alongside traditional bus and shuttle operations.

Dispatchers of such public use of AVs will find themselves with a similar set of problems as the autonomous truck dispatchers. Currently, cities with public transportation networks have existing dispatchers who communicate across networks with drivers of traditional vehicles and maintenance personnel to resolve issues. It is not clear how such dispatch networks will need to change in order to accommodate AVs in terms of staffing, function allocation, and contingency

[3] In February of 2020, NHTSA suspended EasyMile's right to carry passengers in its self-driving shuttles in 10 States, pending a formal review. This occurred because one of the company's 16 autonomous shuttles stopped short at 7mph, leading to the hospitalization of a passenger.

management. Indeed, the issue of heterogeneous vehicle management will likely be more prominent than for long haul trucking given the density and interconnectedness of public transportation networks.

For example, if a city wanted to introduce a small shuttle service on one established service line, it would need to ensure the AV dispatcher was integrated with the other traditional dispatchers for improved communications and team situation awareness. This integration of one or more AVs into public transportation systems dominated by traditional vehicles will also likely require significant equipment and communication upgrades as well as recurrent training.

This scaling of operations represents a cost-related pain point as it would not be cost effective to hire a dispatcher to attend to a single shuttle. Thus, how to balance AV dispatch needs with current dispatch capabilities in the presence of both traditional and AV vehicles, especially for tightly-interconnected public systems, is an area open for study. While there have been various experimental trials of such shuttles around the world, no city has yet integrated such capabilities into their transportation systems so more work is needed in this area.

e. Concept 5: State/Regional AV Management and Dispatch

The last CONOP to be discussed is how the current role of the state/regional government dispatcher would likely change with the arrival of AVs, both cars and trucks. While each state slightly differs in how it provides regional dispatch support, state and regional dispatchers are generally tasked to monitor state-maintained roads to provide assistance in the case of mechanical problems and scheduled maintenance, coordinate with police for events like accidents, and helping coordinate resources for other emergent events like a truck accidentally spilling its cargo across a highway or monitoring the reversal of lanes in an emergency like a hurricane evacuation.

The arrival of AVs is most likely going to affect state/regional dispatchers primarily through the communication function. AV fleets will always have their own dispatchers, either through OEMs and service provides as discussed in CONOPs 1-3 above. However, these fleet management dispatchers will likely need to coordinate with state dispatchers for significant events. As discussed previously, given the relatively high risk of platoons of AVs crossing state highways, state dispatchers will likely experience higher communication and coordination activities as they also monitor the progress of platoons.

In addition, dispatcher monitoring of roadway construction zones and other maintenance activities will likely grow in importance with the arrival of AVs, especially given known limitations of AV vision systems in these environments (Marshall 2017). State/regional dispatchers will also have to coordinate with other private company dispatch teams in the event of a breakdown of such vehicles on state roads to ensure timely and safe clearing of the vehicles.

Such coordination could also potentially have a dramatic positive impact on the timeliness of emergency service response, especially for extreme events such as major accidents or a natural disaster. For example, if a tractor-trailer jackknifes across a major highway with multiple casualties, an OEM fleet dispatcher in coordination with a state dispatcher could very quickly redirect fleets of vehicles under their control, which could clear a faster path for emergency response vehicles. Such actions would likely significantly improve response time over the current state-of-the-art which is notifying human-driven traditional vehicles via dynamic highway message signs or mapping apps that may have significant associated time delay.

In addition to the added communications and monitoring workload AVs will likely bring to state/regional dispatchers, it is likely that their tasking for the remaining functions will also increase, especially training as they will also need to stay current on new capabilities, software updates, and changing protocols. Of the new dispatch functions that AVs could bring, the two that state/regional dispatchers will not routinely encounter are the passenger communications and fleet management functions. Given that the primary job of state/regional dispatchers is to work with dispatchers of both public and private vehicle fleets, this will not generally fall within their realm of responsibility.

The one caveat to this is that occasionally state/regional dispatchers provide some back-up capability for government-owned assets. It is conceivable that for any publicly-managed assets like shuttles and even state-owned driverless cars, one or more state/regional dispatchers may be called upon to provide some emergency backup support, such as clearing shuttles from the scene of an accident through teleoperation or talking with passengers in emergencies.

To summarize, we have elucidated five distinct CONOPs related to the dispatch of autonomous vehicles and trucks: OEM AV Dispatch (1), Robo-Taxi Dispatch (2), Autonomous Truck Dispatch (3), Public Transportation AV Dispatch (4), and State/Regional AV Dispatch (5). The first three CONOPs are private/commercial operations and the last two capture public/government operations. Dispatch centers that represent new capabilities include CONOPs 1 & 2, and those existing dispatch centers that will need to adapt to meet these new needs are CONOPs 3-5.

Table 2 illustrates which of the seven present-day traditional dispatcher functions and the three new AV functions will need to be performed by the same or new dispatchers for each of the five CONOPs. The checkmarks in Table 2 indicate a new functionality and are generally found in dispatch roles for OEM AVs which represent new dispatch opportunities. However, a checkmark is found in Autonomous Truck Dispatch, since trucks already have established dispatch networks but the remote-control element represents a new functionality. This is also true for public transportation and state/regional dispatch centers, so these functions represent new capabilities that would likely have to be integrated into existing systems. The checkmarks in parentheses indicate functionalities that could exist as a backup capability.

Table 2: Functions for Various Dispatcher CONOPs

FUNCTION\CONOPS	OEM AVs (1)	Robo-Taxis (2)	Autonomous Trucks (3)	Public AVs (4)	State/ Regional (5)
Communication	✓	✓	+	+	+
Resource Allocation	✓	✓	+	+	+
Navigation	✓	✓	+	+	+
Contingency Management	✓	✓	+	+	+
Monitoring	✓	✓	+	+	+
Paperwork	✓	✓	+	+	+
Training	✓	✓	+	+	+
Remote Control	✓	✓	✓	✓	(✓)
Passenger Communication	✓	✓		✓	(✓)
Fleet Management	✓	✓	+	✓	(✓)

The plus signs in Table 2 indicate which existing functions are likely to experience increased tasking as AVs become part of operations. Essentially existing surface transportation dispatch centers, either commercial or government, are going to experience increased tasking as AVs and ATs are integrated.

As stated previously, these five different CONOPs are not mutually exclusive and there will likely be a blending of such approaches in the future. For example, Ford has elected to team with Lyft, an on-demand transportation provider, to develop dispatch and management services for future fleets of AVs (Harris 2018). Thus, the new partnership between Ford and Lyft will be a blending of CONOPs 1 and 2, which merge the OEM and Robo-Taxi approaches.

This idea of blending CONOPs and the associated dispatch capabilities will be an important consideration going forward. While existing dispatch operations can provide important lessons learned in the design of new dispatch centers, it may be more difficult to adapt old centers as opposed to developing new ones. Such difficulties could be caused by a resistance to new technologies, unions, costs of adaptation including hardware, software, and personnel training and hiring, the need for more space etc. Thus, it is important for companies and agencies to carefully plan in advance of such technology integrations.

In order to more fully understand how such changes could affect existing dispatch capabilities, the next section of this report builds a model of state/regional dispatchers' current operations and illustrates how this could change with the arrival of AVs. This approach also further explores how optimal dispatch staffing models could be developed, including function allocation and team design.

5. Detailed Workload Model for State/Regional Dispatcher Managing AVs

As previously discussed, one issue that is important to consider given the pending integration of AVs into surface transportation environments is how such additions could affect existing operations. Unfortunately, given that AV systems are still in testing phases and it is not clear when and how such sustained operations will be achieved, any predictions of future dispatcher performance will need to be estimated. To this end, we developed a validated model of current state/regional dispatch operations and then extended it to determine worst-case scenarios of how dispatcher workload would likely be impacted by the introduction of AVs.

In order to develop a model of current dispatch operations, we elected to focus on CONOP 5 from the previous section, which looked at how state/regional dispatch operations would likely change as a result of both AV passenger and truck operations. By developing and validating a model of current dispatch operations using the seven functions previously outlined and then incorporating the three new functions attributed to AV operations, we can begin to understand what the likely impact could be on existing dispatch operations. To this end, we elected to use a discrete event simulation (DES) technique. Such DES models have been successfully applied to similar dispatch settings like air traffic control (Bevilacqua, Ciarapica et al. 2012), and ambulance and rail dispatch (Lam, Zhang et al. 2014, Huang, Cummings et al. 2018).

DES models are based on queuing-based constructs where events build up in a queue to be serviced by a dispatcher. DES models include events (e.g., the occurrence of a problem), arrival processes (e.g., how often problems must be addressed by dispatchers), service processes (e.g., how long it takes a dispatcher to solve a problem), and queuing policies (the priority dispatchers give to incoming problems). The arrival frequencies of events and service processes are based on probabilistic distributions and priorities in task handling. For example, emergency events go to the head of the queue. Both the kinds of events that arrive to be handled by dispatchers, and the resulting tasks that need to be incorporated in the model are derived from an in-depth task analysis. Through interviews, observations, and document reviews, a task analysis determines the tasks that dispatchers must accomplish, as well as priorities and strategies used by dispatchers to handle complex issues.

To determine those tasks that should be modeled in state/regional dispatch operations, we interviewed multiple transportation stakeholders included personnel from the North Carolina Turnpike Authority (NCTA), which is especially important given NCTA's designation as a proving ground pilot site for the testing of automated vehicle technologies. To this end, five clusters of tasks (Figure 4) were determined to be the typical tasks for a regional dispatcher whose job it was to coordinate activities across a turnpike. There are five groupings to elucidate the priority scheme for task importance, and the starred entries indicate where the three new functions related to AV management would fall.

Once the tasks are elucidated, the next step is determining the frequency of the task type, as well as how long it takes a typical dispatcher to complete each task. Appendix A details the frequencies and service times of each of these tasks. Another important parameter contained in Appendix A is how long each task can wait to be completed. For example, if a major incident occurs such as the loss of cargo from the back of a truck that blocks the highway, it is important to understand how long the other tasks can wait. Paperwork can wait an entire shift under emergency circumstances, but on average, the longest the task of posting a dynamic message on an overhead sign can wait is 7 minutes before it must be completed.

One other important parameter that must be considered in the development of a regional dispatcher model is the difference between activated and non-activated operations. Normal operations are known as non-activated conditions but when a major event occurs, like when roads need to be reversed to facilitate hurricane evacuation, then the entire dispatch center moves into an activated state. This is a formal distinction that is important to consider since it changes operational procedures and priorities. Because of this, Appendix A contains both frequencies and service times for the activated (emergency) operations and the non-activated (normal) operations.

Once the tasks, their frequencies and service time distributions, and queuing priorities are known, they can be inserted into a discrete event simulation that can run thousands of simulations to understand many key performance parameters, such as average wait times of different tasks and how many tasks get accomplished over some period of time. Another important metric than can be derived from such simulations is how much time operators spend on various tasks, which can be used to determine overall staffing implications and potentially unsafe periods of operation when operator workload may be too high or too low.

The following sections will address the development of models for current and future regional dispatch operations, and also discuss the workload implications.

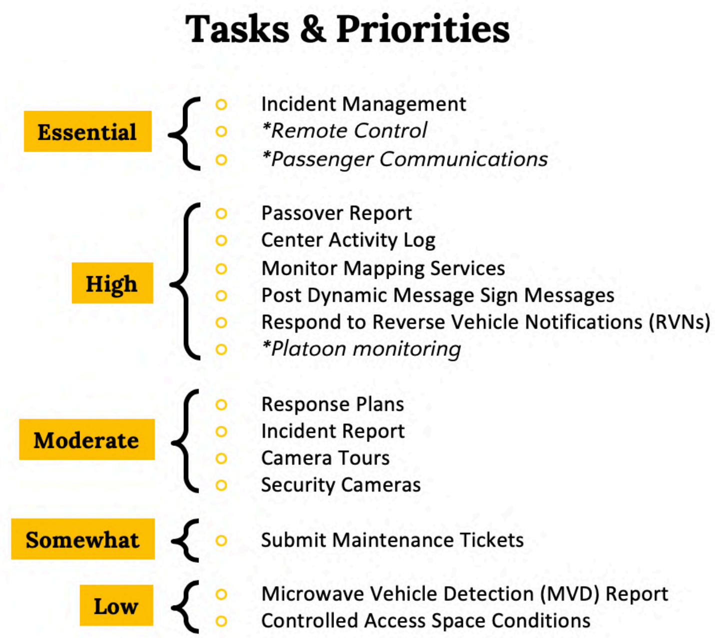

Figure 4: Representative Tasks for a Regional Dispatcher

a. Single Dispatcher Operations

While there are various commercial DES packages that could be used to develop such models, we adapted an open-source, previously-developed DES called SHADO[4] (Simulator of Humans and Automation in Dispatch Operations), originally designed for rail and aviation dispatch applications. This DES application takes in task arrival frequencies, operator service times, and task priority schemes to generate data and visualizations that indicate overall average workload for a dispatcher's shift. SHADO also outputs how this workload is distributed by task. The original SHADO model also has the ability to estimate human errors for rail dispatchers, but this function was not used due to a lack of error data for surface transportation dispatchers.

[4] http://apps.hal.pratt.duke.edu/shado-webdev/

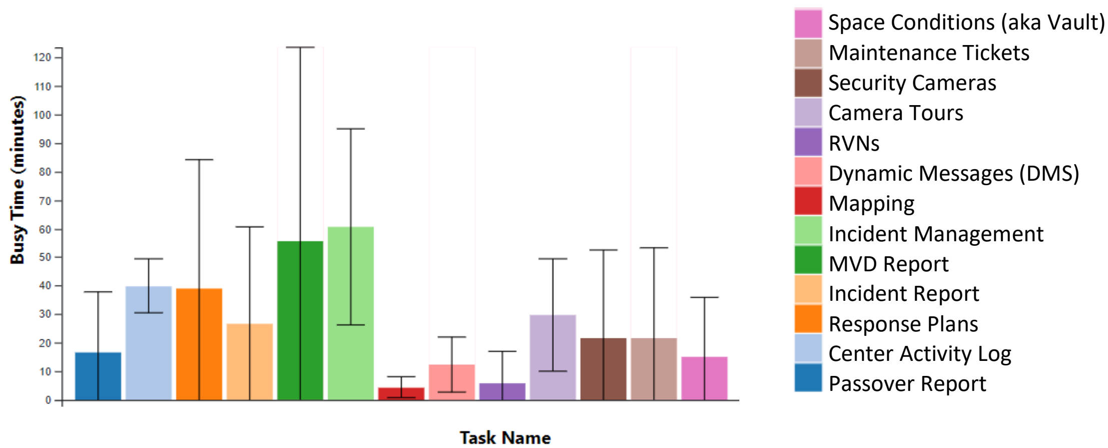

Figure 5: Average non-activated dispatch service time per task, with one standard deviation depicted.

Take the case of a single dispatcher executing the tasks outlined in Figure 4 under non-activated conditions, but only considering current operations (so ignoring the starred conditions). Using SHADO and running 2000 replications of the model, Figure 5 illustrates, on average, how much time is typically spent over an average 8-hour shift on each of the present-day tasks. The exact field entry details are given in Appendix B.1. Figure 5 reveals very useful information as to how dispatchers are currently spending their time. Incident management and attending to emergent roadside events requires the most effort, followed by microwave vehicle detection reports, which vary widely across different shifts.

Overall utilization for a single dispatcher under normal conditions is depicted in Figure 6a. Utilization is a workload metric that measures a person's percent busy time over some time period. For example, if a dispatcher is actively tasked to work 4 hours out of an 8-hour shift, the utilization is 50%. While utilization can be a dynamic measure, previous research has shown that

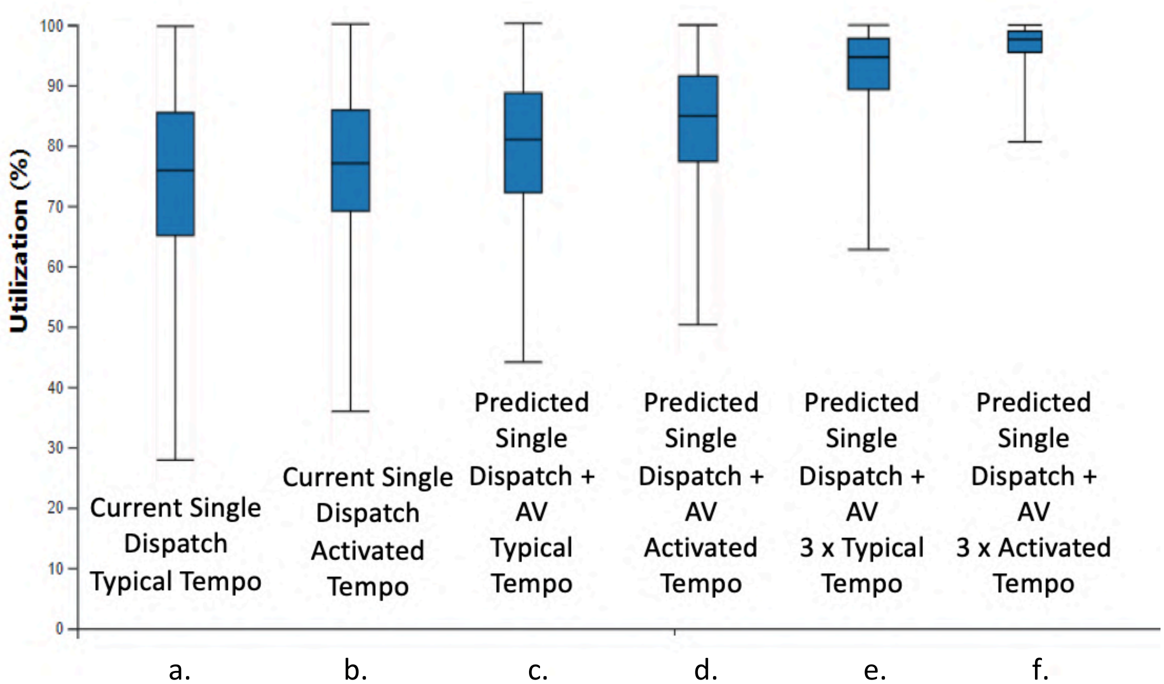

Figure 6: Utilizations for a single dispatcher across increasingly complex scenarios

sustained operations above 70% can lead to overworked operators, while sustained utilizations below 30% should be avoided due to boredom and distraction (Yerkes and Dodson 1908, Rouse 1977, Donmez, Nehme et al. 2010, Cummings and Gao 2016). Given this metric, it can be seen that, on average, single dispatchers in this setting are roughly tasked to about 76% of their capacity under non-activated conditions.

When the model was run again using the input distributions in Appendix A for the activated (i.e., emergency) operations, which occur about a half-dozen times per year, the utilization metric increases quite a bit for the single dispatcher, as illustrated in Figure 6b. While non-activated operations hovered just above the high workload threshold, activated operations clearly increased single dispatcher task demands. As will be discussed in a subsequent section, because of such high workload, often other dispatchers are brought in to assist in high times of workload.

Once the SHADO models for non-activated and activated operations for a single dispatcher were developed, they were evaluated by actual dispatchers and modified until the dispatchers felt the models reflected actual operations. Such validations build confidence in the models and are an important step before they can be used prospectively (Law and Kelton 2000).

Once the model was validated, we incorporated the three AV functions previously discussed, platoon monitoring, some remote control of state-owned vehicles, and some passenger communications. It is worth noting that while platoon monitoring would be a commonly-occurring task, remote control and passenger communications represent special cases for a state/regional dispatcher that would likely occur under atypical circumstances. Because there is no public data available on the frequencies and service times associated with such AV dispatch tasks, we made what seemed to be reasonable and conservative estimates for each of the three functions in non-activated and activated operations. The AV task frequencies and service times for the dispatcher models included roughly 4-5 interactions per day with individual AVs and brief checks on platooning trucks 3 times an hour, details are in Appendix A. These times resulted in the utilization plots in Figures 6c and 6d, and the task time plots are detailed in Appendix B1.

Given the already marginally-high workload of a single dispatcher under non-activated conditions, it is not surprising that when some AV operations are added to the functions for which the dispatcher is responsible, the average workload grows to approximately 82% in Figure 6c, an 8% growth over the present-day non-activated conditions. When AV operations are added to the task demands for a single dispatcher in activated conditions, the average workload rises to ~84% in Figure 6d, also indicating an 8% increase in workload over present-day conditions. It should be noted that the assumptions for this regional dispatcher model include infrequent interactions with AVs and occasional monitoring of platooning trucks. Models of dedicated AV dispatchers that require frequent interaction with AVs would likely show much higher utilizations.

The workload predictions in Figure 6 are predicated on the assumption that the underlying autonomy on both cars and trucks operates similarly to human drivers in terms of pace, meaning that the AVs are not overly conservative in their decision making. Uber recently announced its self-driving cars will be more cautious after one of their cars was involved in the death of a pedestrian (Somerville 2018). While more conservative cars are thought to be safer, simulations have shown that overly-cautious AVs can lead to increased traffic congestion (Li, Seth et al. 2020). Increased congestion could lead to higher workload for dispatchers as more cars could be involved in accidents and AVs may need more attention.

In order to account for possible increases in dispatcher workload due to overly-cautious AVs, which represents a worst-case scenario, the frequencies and service times of the three AV functions were tripled. This increase was selected since previous research demonstrated that traffic conflicts would likely increase roughly three-fold if approximately 33% of cars on the road were AVs (Li, Seth et al. 2020). The plots in Figures 6e and 6f demonstrate how dispatcher workload would likely be affected in the non-activated and activated conditions. Not surprisingly, the utilization levels are just shy of 100% (93% and 97% respectively), suggesting dispatchers could not safely do their job.

The increasing trend for Figure 6 illustrates several important points. First, for regional dispatchers who are only expected to interact with AVs intermittently and under contingency operations, their workload will increase ~8%. Under current workload conditions for this regional center, as AVs start to become part of the transportation network systems, they could overwhelm existing dispatch operations. One possible solution is to bring in another dispatcher, which already occurs in many centers during activated operations. The next section will demonstrate how these workload profiles change when an additional dispatcher is added.

b. Two Dispatcher Operations

As discussed previously, dispatch centers will often bring in additional people when task demand is high, particularly under contingency operations. To understand how such staffing arrangements could affect operations, several models were constructed for teams of two dispatchers managing

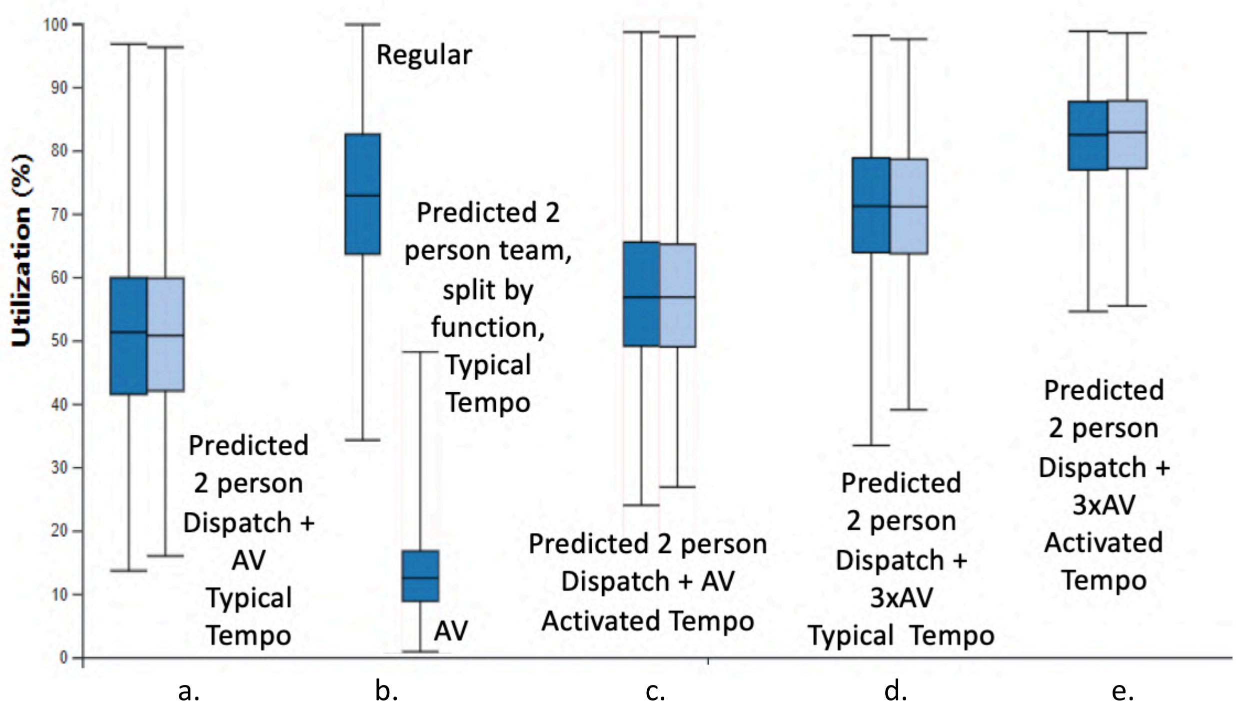

Figure 7. Utilizations of Two Dispatcher Models for Increasingly Complex Scenarios

regional center operation with the addition of AVs. These are depicted in Figure 7, with detailed discussions following.

The first model generated, Figure 7a, demonstrates the workload of two dispatchers under normal conditions with the added of workload of managing AVs. The assumption for the team of two in Figure 7a is that both dispatchers are qualified to handle any incoming task, but there is additional communication overhead as dispatchers must discuss who will do what task and on what timeline. The added workload of team communication has been well documented in previous research (MacMillan, Entin et al. 2004). Appendix D includes all the task time breakdowns for Figure 7.

As can be seen in Figure 7a, the average utilization of both dispatchers sharing tasks, including AV tasks, drops to about 54%, which is an improvement over the average of 82% utilization of the single dispatcher doing the same tasks (Figure 6c). While this is a substantial improvement, it should be noted that it was not a bigger drop due to communication and coordination overhead. However, having both dispatchers qualified to handle and share all tasks is not the only approach to such teaming operations, as one possible arrangement could be that a new dispatcher is hired to only handle those tasks specific to AVs.

It is a common supposition that if a new capability like AVs arrives, then dispatch centers should just add another dispatcher specially trained to only handle AV issues. This would, in theory, save in training costs and would be the least disruptive to operations. So, to examine how this kind of CONOP would influence both the regular dispatcher and a new dedicated dispatcher who only handled AV functions, we modeled such an arrangement with results depicted in Figure 7b. Not surprisingly, the regular dispatcher's utilization is still high at about 76% and the AV dispatcher, with only three intermittent functions to manage, has an average utilization of 15%, although upon occasion, it can approach 50%. Not shown here, but included in Appendix D, under activated conditions the average workload for this dedicated AV dispatcher rises to only 20%.

As discussed previously, it is not advisable for dispatchers to work below 30% due to boredom and the increased likelihood of distraction. Moreover, it is also not cost effective to hire a person to only work 15% of a shift. While private companies who embody CONOPS 1 and 2 will need dispatch centers full of dedicated AV dispatchers, regional government centers will not have the same demand, especially when AVs are a low percentage of overall numbers of cars on the road. Thus, such a CONOP of splitting tasks functionally would not be advisable for a regional dispatch center until there was enough market saturation of AVs to generate at least a relatively consistent 30% or higher utilization load.

This issue of whether to cross-train for tasks across traditional and autonomous vehicle functions has other implications that deserve further study. One such issue is the perishability of occasionally-used skill sets and what the recurrent training requirements would be, especially for those skills that are only infrequently used. For example, if regional dispatchers only interact with AVs on rare occasions, it is possible they could forget what the correct procedures are. These problems also occur in similar safety-critical settings like air traffic control, and previous research has demonstrated that current refresher training programs fall short when preparing controllers for rare emergency events (Malakis and Kontogiannis 2012). Such additional training costs would likely play into staffing decisions and whether some functions could or should be subcontracted to other companies.

Given that there are a few times a year where the regional dispatch center experiences extremely high workload due to emergency situations like hurricanes, called activated operations, we developed SHADO models of teams of 2 dispatchers handling activated loads including AVs under the shared tasking paradigm (Figure 7c). In addition, we also generated models of the most extreme case of teams of dispatchers jointly supervising cautious AVs in non-activated and activated scenarios (Figures 7d and 7e, respectively).

The most striking finding from the models of teams of two dispatchers under these high workload scenarios (Figure 7c-d) is that both dispatchers' utilizations do not exceed 70%. Even in the worst possible case (Figure 7e), the average utilization does not exceed 83%. This suggests that teams that share tasks are much more resilient to unusual circumstances, and such findings have been found in other domains (Mekdeci and Cummings 2009, Gao, Cummings et al. 2016). Thus, teams of two dispatchers provide a layer of robustness to fluctuations in tasking that single dispatchers cannot provide. However, it should be noted that in all cases, the team workload can go to 100%, suggesting the need to bring in yet a third person to the team. However, such cases are extreme and represent exceedingly rare events.

6. Conclusion

Once reliable vehicle-to-vehicle (V-to-V) and vehicle-to-infrastructure (V-to-I) networks are established, remote fleet management could aid in improved traffic flow as well as improving first response times for emergent situations that arise such as crashes or extreme weather events. Remote fleet managers of the future will monitor real-time traffic flows, ensure that disabled or crashed AVs receive assistance (including possibly taking control of individual vehicles), while also potentially redirecting traffic away from emergent events. Because these futuristic operators will have the ability to directly communicate with some, but not all, cars, they may be able to immediately communicate with equipped cars through the V-to-V network when problems emerge or congestion is high. Moreover, they may be able to change external signs and signals in order to communicate with non-equipped vehicles to ease traffic congestion and aid in emergency response.

Remote fleet management of AVs will require an operations center staffed by personnel that resemble surface transportation dispatchers today, but these operators will have significantly more responsibilities. To this end, this report outlined three new functionalities unique to AV dispatchers as well as five broad Concepts of Operation (CONOPs) that illustrate how AV fleet management could develop, including **Original Equipment Manufacturing (OEM) AV Dispatch Support, Robo-Taxi Dispatch, Autonomous Trucking Dispatch, Public Transportation AV Dispatch,** and **State/Regional AV Management and Dispatch.**

The first three CONOPs focus on private/commercial operations while the latter two represent public/government operations. Given that such fleets are still futuristic and not yet implemented beyond small test sites, it is still unclear how such capabilities will develop. It is possible that elements of these CONOPs could be combined, e.g., it is possible that public-private partnerships could emerge where OEM developers augment public transportation dispatch centers with personnel that specialize in AV operations. However, how such centers should be staffed requires an understanding of AV market saturation as well as reliability of the underlying autonomy and frequency of critical events.

To better understand staffing and workload implications of AV dispatch tasking, a case study was developed that looked at how the arrival of AVs could impact a regional dispatch center. A discrete event simulation that focuses on dispatcher workload yielded several models that examined both single and two-person dispatcher teams under both typical and emergency operations. These models indicated that even with minimal new tasking caused by the arrival of AVs, the additional workload would likely be too much for a single dispatcher, even under a normal operational tempo, and so an additional dispatcher would likely be needed.

It was further demonstrated that in order to ensure dispatchers had enough to do and would not be bored and distracted, in this specific regional dispatch center example, it would be better for dispatchers to share tasks instead of one focusing on typical tasks and one specializing in AVs. While there would likely be additional training costs including possibly refresher training, this case study demonstrated that teams of two dispatchers that share tasking provide a level of robustness to emerging events and prevent workload from rising at untenable rates.

It should be noted that these results are only specific to this case study, and every agency or company would need to run similar models to develop their own estimates tailored to their unique operational architectures. Moreover, such models at this point in time contain many assumptions as to the performance capabilities of AVs and these models cannot be considered precise until better data is available to estimate AV capabilities and remote ground control station capabilities, network latencies, etc.

Going forward, companies and government agencies should start developing such models, understanding that they can only provide broad estimates for future operational needs. However, as time goes on and AV technology improves, including 5G and other connectivity networks, these models can be updated to generate more precise estimates. Lastly, because the introduction of AVs will introduce many new issues for dispatchers of all types, it is critical that agencies share best practices as well as data from such models and actual operations so that the entire surface transportation network can benefit.

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Appendix A

SHADO Simulation Parameters. All units are in minutes.

#	Task Name	NON-ACTIVATED STATE			ACTIVATED STATE		
		Frequency	Wait time	Time to completion	Frequency	Wait time	Time to completion
1	Passover Report	400	whole shift	avg 15	400	whole shift	avg 15
2	Center Activity Log	12	120	avg 1	120	120	1 to 10
3	Response Plans	300	whole shift	avg 30	not applicable		
4	Incident Report	300	120	avg 30	130	120	avg 30
5	MVD Report	400	whole shift	avg 60	not applicable		
6	Incident Management	150	1 to 31	10 to 30	120	1 to 31	10 to 30
7	Mapping Services	150	30	2 to 3	150	140	25 to 120
8	Direct Messages	48	7	avg 3	40	7	avg 3
9	Respond to RVNs	350	12	avg 10	250	12	avg 10
10	Camera Tours	30	10	avg 5	30	10	avg 5
11	Security Cameras	400	180	avg 30	400	180	avg 30
12	Maintenance tickets	150	180	avg 10	120	120	avg 10
13	Space Conditions	400	whole shift	avg 15	60	whole shift	avg 5
AV-specific Tasks							
14	Remote Control	100	1	avg 20	75	1	avg 20
15	Passenger Communication	100	7	1 to 5	75	7	1 to 5
16	Platoon Monitor	20	30	avg 5	15	25	avg 5

Appendix B

B.1 SHADO Field Entries for Single Dispatcher Models

- Schedule & Domain: Morning, General
- Shift: 8 hrs, no shift transition, no extreme conditions, 2000 Days
- Tasks: Default tasks deleted, add the following functions with the parameters in Appendix A:
  - Passover Report
  - STOC Activity Log
  - Response Plans
  - Incident Report
  - MVD Report
  - Incident management
  - Mapping
  - Post DMS Messages
  - Respond to RVNs
  - Camera Tours
  - Security Cameras
  - Submit MOMs Tickets
  - Vault Conditions
  - Teleoperation
  - Passenger Communication
  - Platooning
- Fleets: Fleet settings = 1 Fleet, ignore Fleet 1, select “Other Sources”, select all added tasks, no different traffic levels
- Operators: 1 Team, no flex team, team size 1, priority strategy from Figure 4, select all tasks from other sources (ignore fleet, error and AI modeling)

B.2 SHADO Field Entries for Two Dispatcher Models

- Schedule & Domain: Morning, General
- Shift: 8 hrs, no shift transition, no extreme conditions, 2000 Days
- Tasks: Default tasks deleted, add the following functions with the parameters in Appendix A:
  - Passover Report
  - STOC Activity Log
  - Response Plans
  - Incident Report
  - MVD Report
  - Incident management
  - Mapping
  - Post DMS Messages
  - Respond to RVNs
  - Camera Tours
  - Security Cameras
  - Submit MOMs Tickets
  - Vault Conditions
  - Teleoperation
  - Passenger Communication
  - Platooning
- Fleets: Fleet settings = 1 Fleet, ignore Fleet 1, select “Other Sources”, select all added tasks, no different traffic levels
- Operators: 1 Team, no flex team, team size 2, priority strategy from Figure 4, select all tasks from other sources (ignore fleet, error and AI modeling)

Appendix C

Utilization descriptive statistics and breakdown of dispatchers' tasks for Figure 6 models a - f.

% Utilization	Mean	Median	Stan Dev.	Min	Max
Current Single Dispatcher – Non-activated	76.16	76.71	15.32	21.01	99.96
Current Single Dispatcher –Activated	75.87	76.79	12.29	38.86	99.87
Predicted Single Dispatcher – Non-activated	82.16	83.36	16.76	46.19	99.99
Predicted Single Dispatcher – Activated	83.98	84.60	10.49	49.38	100.00
Predicted Single Dispatcher – 3 x Non-activated	92.81	94.28	6.11	61.65	100.00
Predicted Single Dispatcher – 3 x Activated	96.83	97.66	2.66	78.76	100.00

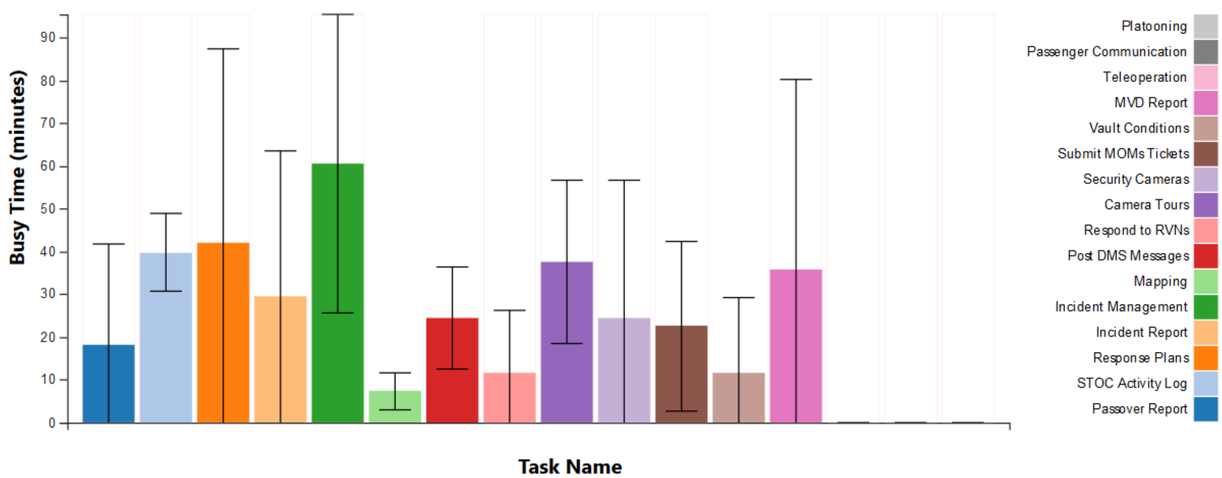


Figure 6a. Task times for current single person dispatch with under non-activated conditions

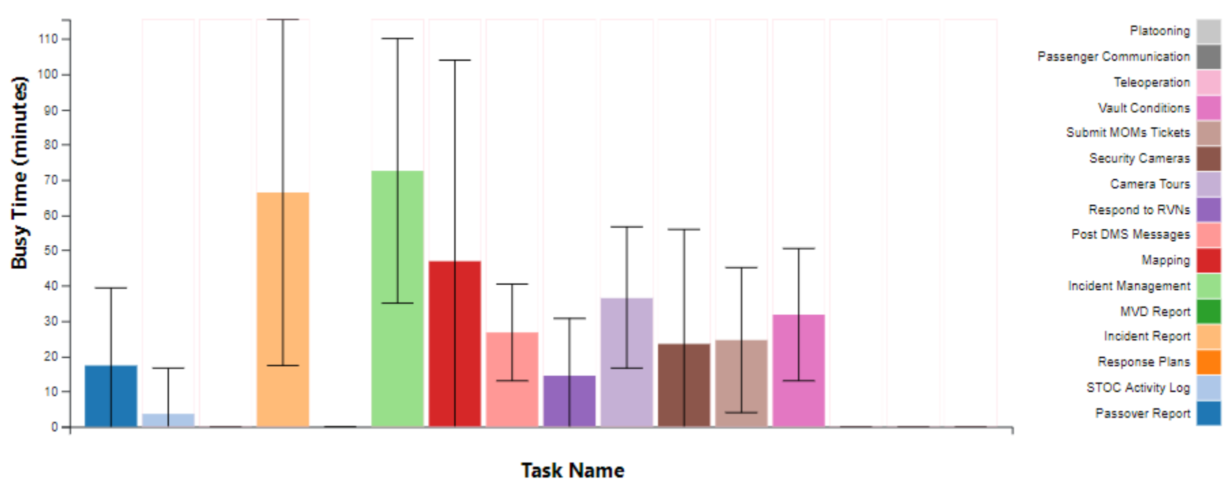


Figure 6b. Task times for current single person dispatch with under activated conditions

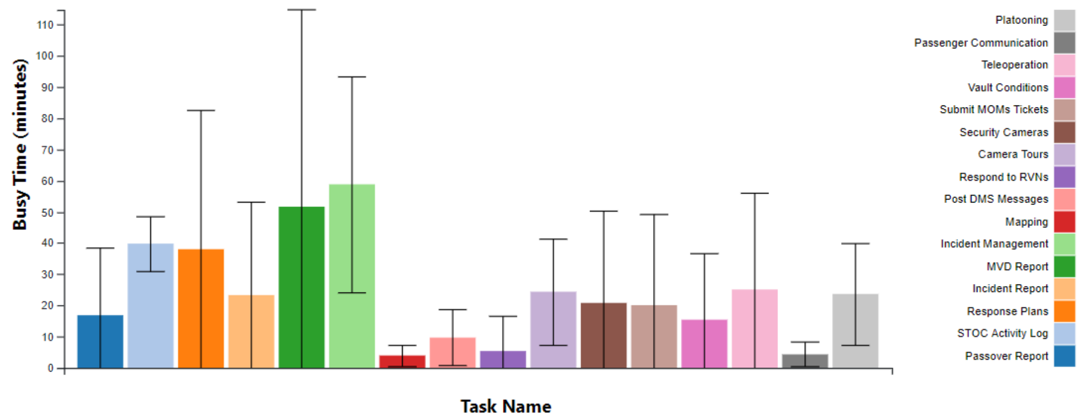


Figure 6c. Task times for predicted single person dispatch with AV tasks under non-activated conditions

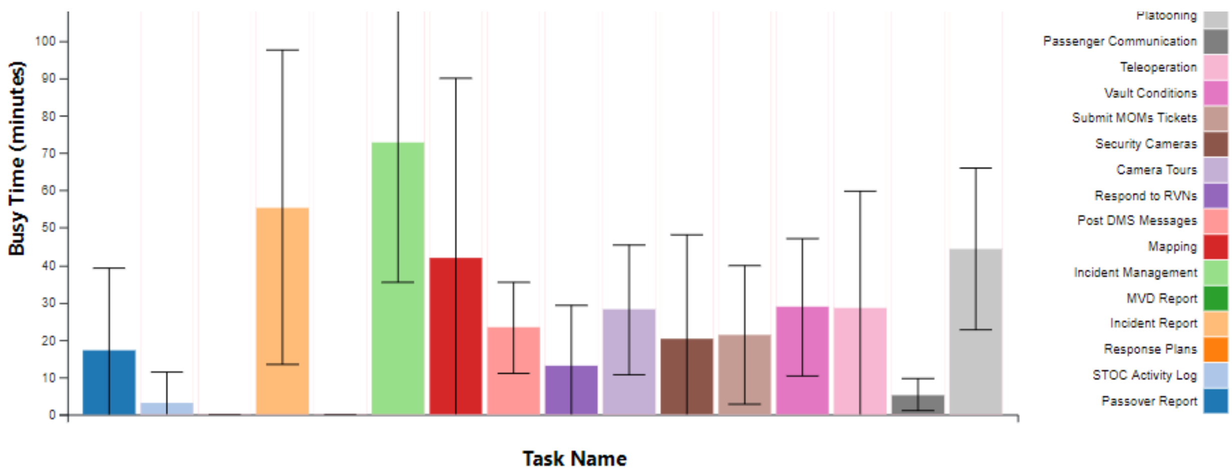


Figure 6d. Task times for predicted single person dispatch with AV tasks under activated conditions

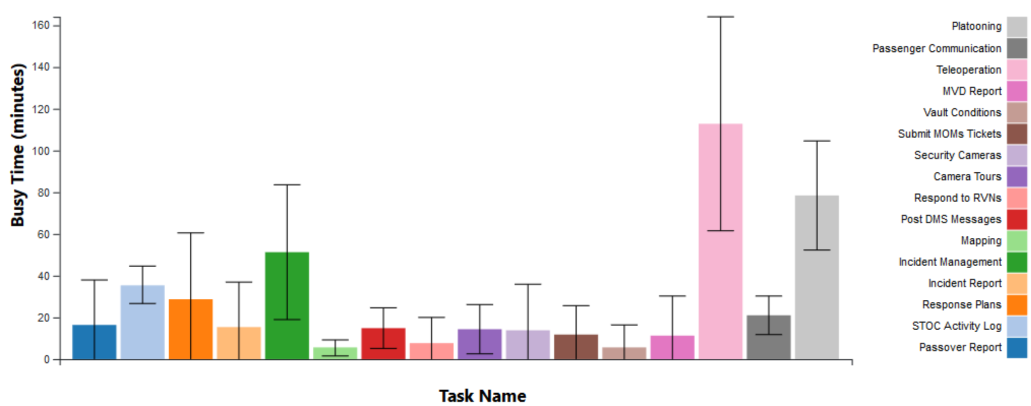


Figure 6e. Task times for predicted single person dispatch with triple frequencies of AV tasks under non-activated conditions

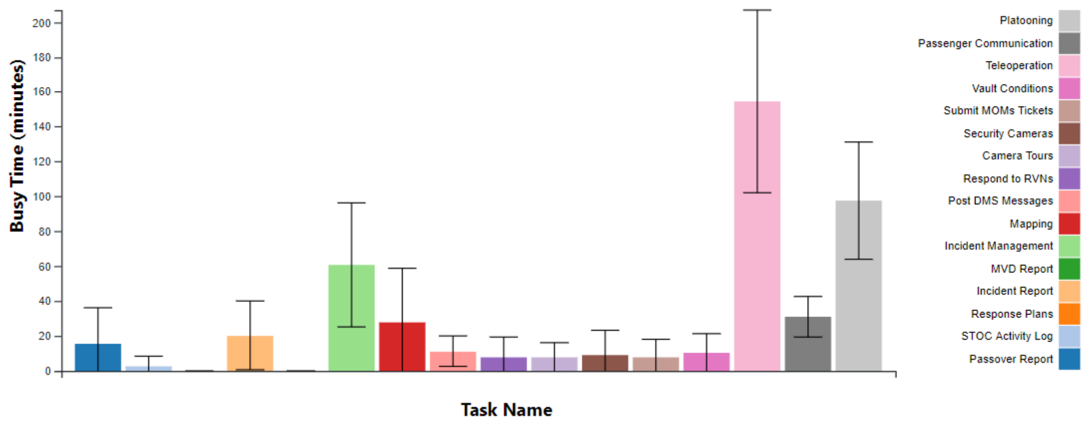


Figure 6f. Task times for predicted single person dispatch with triple frequencies of AV tasks under activated conditions

Appendix D

Utilization descriptive statistics (average for two dispatchers) and breakdown of dispatchers' tasks for Figure 7 models a – e

% Utilization	Mean	Median	Stan Dev.	Min	Max
Predicted Two Dispatchers – Non-activated	53.91	52.95	13.125	19.18	98.73
Predicted Dedicated Regular Dispatcher – Non-activated	75.71	76.19	15.16	32.81	99.99
Predicted Dedicated AV Dispatcher – Non-activated	15.03	13.47	7.07	1.05	53.96
Predicted Dedicated Regular Dispatcher – Activated*	76.23	77.03	12.50	36.73	99.94
Predicted Dedicated AV Dispatcher – Activated*	19.90	18.72	8.54	1.94	53.69
Predicted Two Dispatchers – Activated	56.26	55.45	12.18	23.18	98.80
Predicted Two Dispatchers – 3 x Non-activated	70.94	70.67	11.42	37.75	99.73
Predicted Two Dispatchers – 3 x Activated	82.35	82.53	8.24	53.77	99.70

*Not shown in Figure 7b.

The following graphs represent the combined times for both people on a dispatch team.

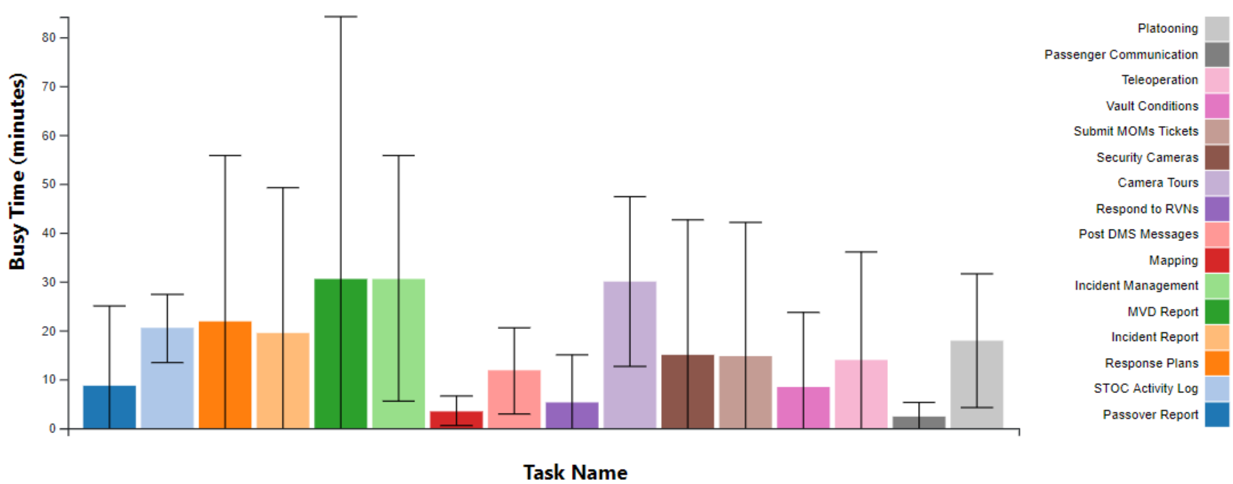
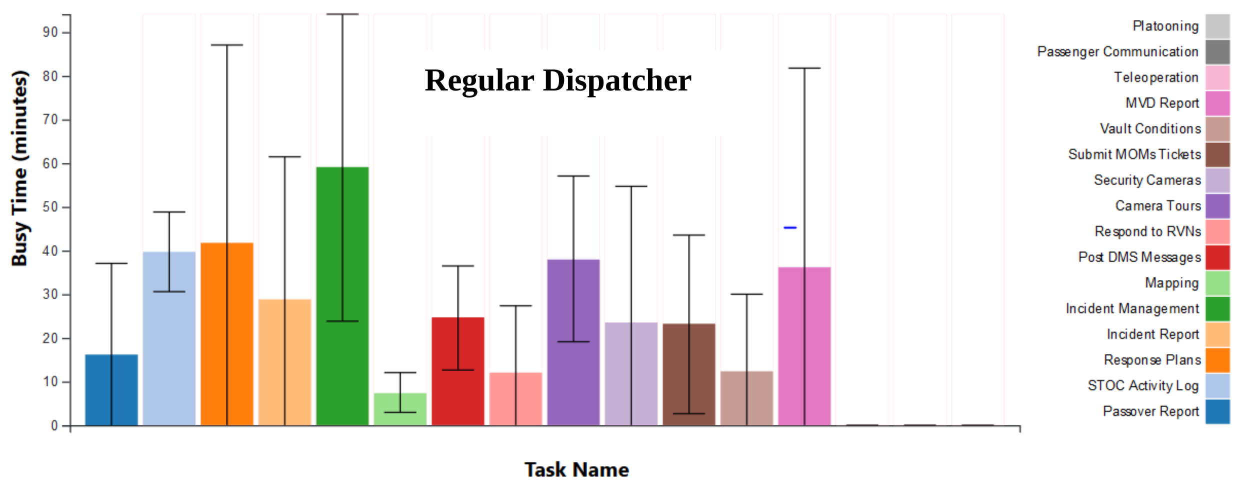


Figure 7a. Task times for predicted 2-person dispatch with AV tasks under non-activated conditions



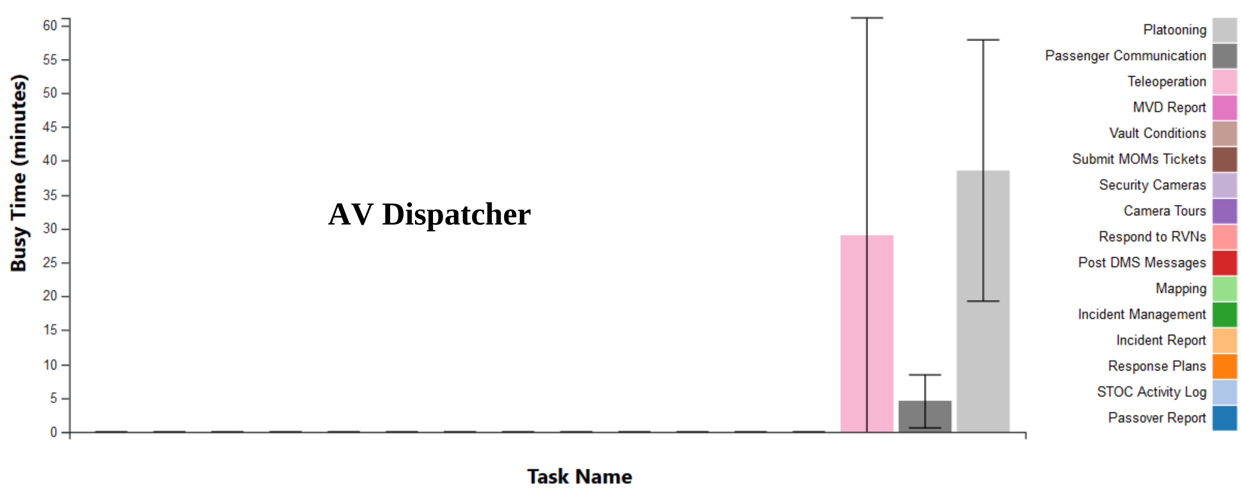


Figure 7b. Task times for predicted dedicated regular person dispatch teamed with dedicated AV dispatcher tasks under non-activated conditions

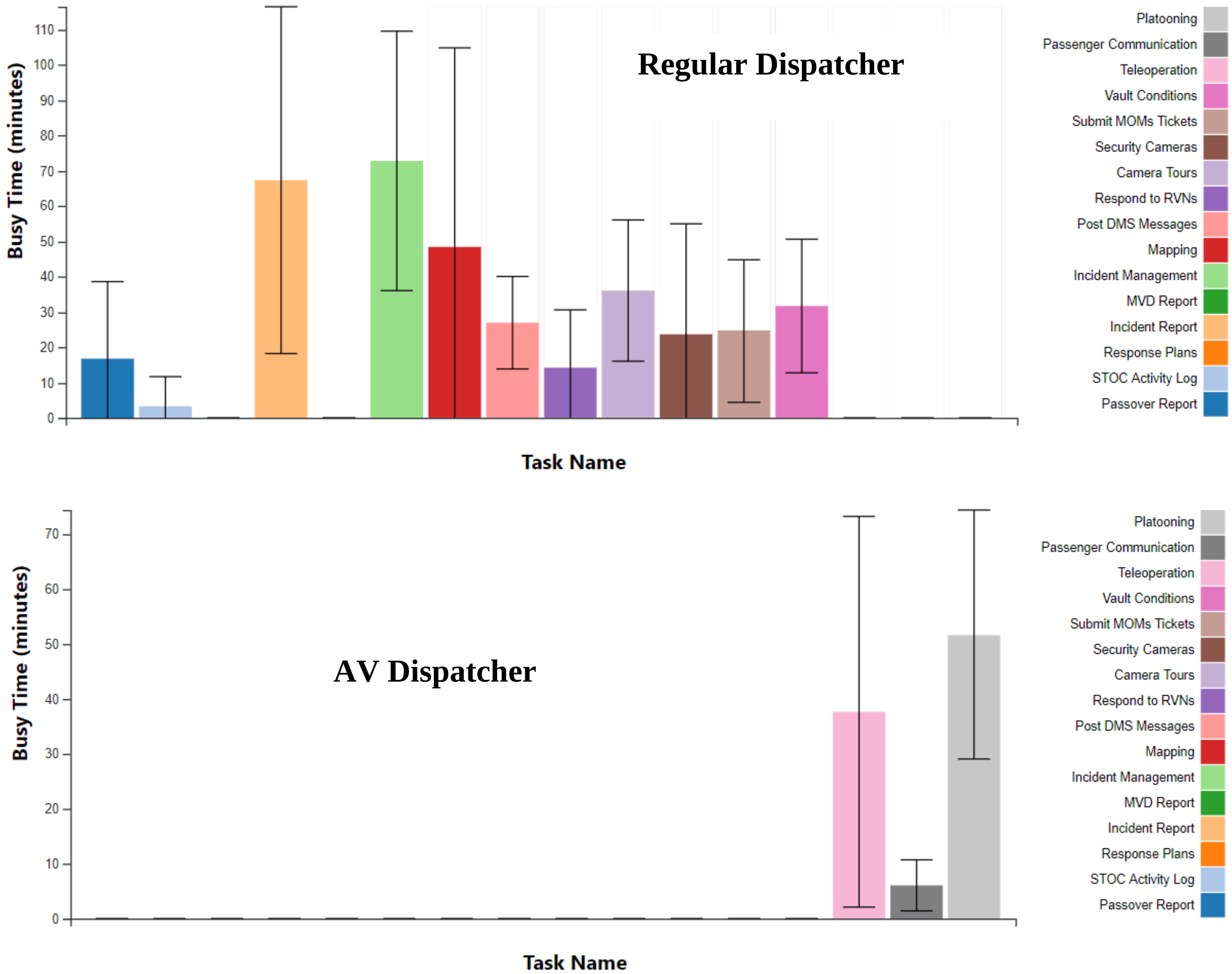


Figure 7b-2. Task times for predicted dedicated regular person dispatch teamed with dedicated AV dispatcher tasks under activated conditions. Not shown in Figure 7b.

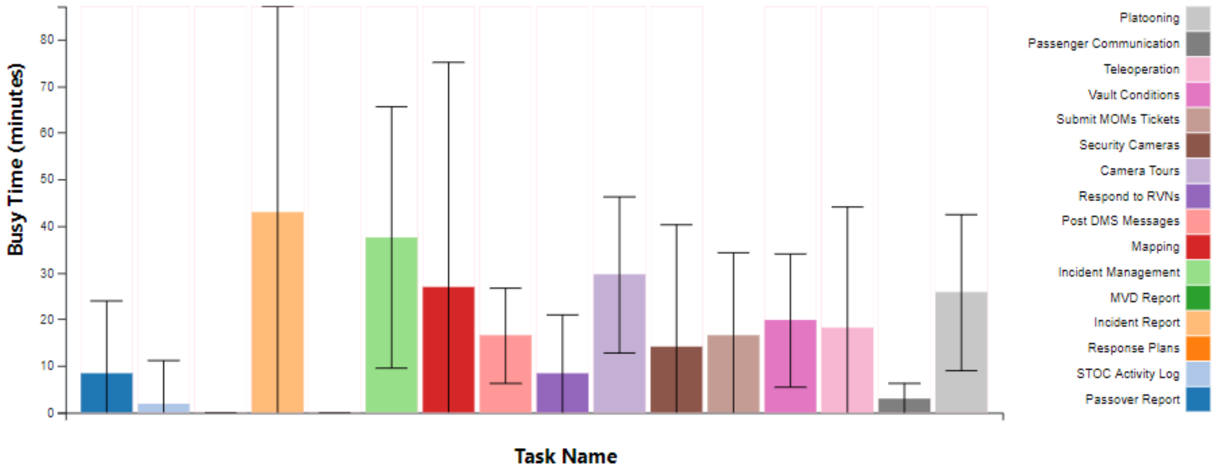


Figure 7c. Task times for predicted 2-person dispatch with AV tasks under activated conditions

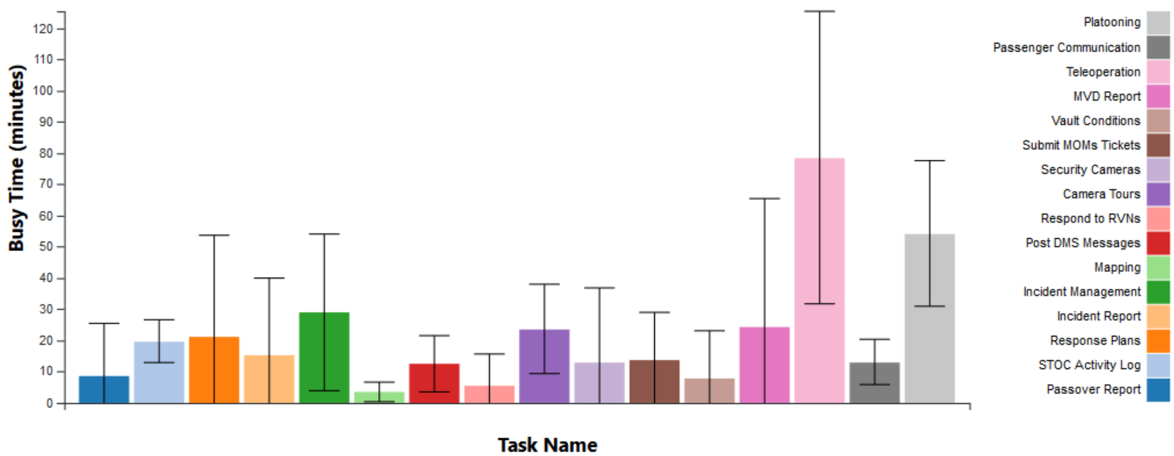


Figure 7d. Task times for predicted 2-person dispatch with triple frequencies of AV tasks under non-activated conditions

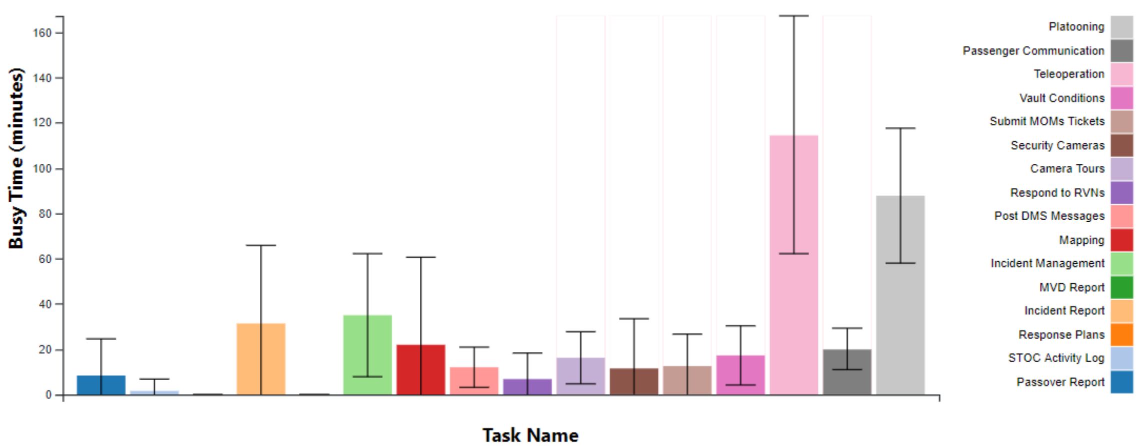


Figure 7e. Task times for predicted 2-person dispatch with triple frequencies of AV tasks under activated conditions