Trucking Fleet Concept of Operations for Automated Driving System-equipped Commercial Motor Vehicles

Chapter 3: Operational Use Cases

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Abstract

Automated Driving Systems (ADS) are set to revolutionize the transportation system. In this project, the research team led by the Virginia Tech Transportation Institute developed and documented a concept of operations (CONOPS) that informs the trucking industry, government agencies, and non-government associations on the benefits of ADS and the best practices for implementing this technology into fleet operations.

The research team demonstrated the implications of implementing ADS technologies across three operational use cases, including public roads and private intermodal ports. ADS capabilities were evaluated using human factors analyses of organizational elements and roles through collected observational and interview data to evaluate the impacts of automation implementation. This approach describes a baseline evaluation of the organization before automation, and the subsequent analysis following the gradual implementation of autonomous vehicles. The analyses address both organizational and individual elements, integrating them into a macro cognitive model that examines human involvement within their tasks and roles.

This report is valuable for fleets, policymakers, ADS developers and the public, offering insights into the challenges and benefits of implementing ADS in a manner that is safe and efficient for all road users.

The following chapter has been extracted from the final report. For access to the full report, see this link: https://www.vtti.vt.edu/PDFs/conops/VTTI_ADS-Trucking_CONOPS_Final-Report.pdf

3. OPERATIONAL USE CASES

3.1 PORT OF OAKLAND – AUTONOMOUS QUEUEING DEMONSTRATION

There is a growing problem of increasing wait times at U.S. ports and other major shipping facilities. In the past decade, container ships have gotten considerably larger. The number of 20-foot containers that these mega container ships can carry has grown from 8,000 or so to more than 20,000 containers. Port improvements, and technologies, including reservation systems for trucks, have not been able to keep pace with the sheer number of shipping containers. As a result, wait times for loading and unloading containers onto trucks have increased considerably; in some cases, a driver must wait more than 6 hours (Figure 10). Wait times reduce driver and carrier productivity because they diminish a driver's available hours of service (HOS). Typically, a commercial driver can drive a total of 11 hours in a 14-hour workday. When paid by the mile, as most commercial drivers are paid, increased wait times can greatly reduce driver earnings.

Figure 1. Photo. Typical truck queueing at U.S. ports.

ADS offer the potential to allow the vehicle to drive itself in "Level 4" mode while queueing to be loaded or unloaded. With an ADS-equipped truck, a driver could go off duty and rest in a sleeper berth or leave the ADS to obtain rest in a motel or port facility. Since the waiting would be used for rest, it would not count against the driver's HOS, thereby increasing the driver's overall productivity, the carrier's bottom line (more distance could be covered in the day), and safety (drivers would be better rested and less pressured by time). Alternatively, for local delivery, it could change the operations at port facilities. A driver could manually drive the truck in city traffic to the port waiting line, then switch the truck into autonomous mode and pick up an already loaded ADS-equipped vehicle. This could greatly increase the number of turns that a driver could make in a workday.

As a first step towards addressing the problem of wait times at ports and demonstrating how ADS technology could be safely deployed in a port queuing operational design domain (ODD), the VTTI study team conducted an autonomous queueing deployment at the Port of Oakland in

Oakland, California. The study team conducted considerable outreach for this deployment. The team briefed principals within the FMCSA and Maritime Administration (MARAD) regarding the study effort and the Port Queuing demonstration. MARAD assisted VTTI with briefing the port facilities in Northern California, including project managers at the Port of Oakland. The team also briefed the California Highway Patrol, California Department of Motor Vehicles, and California Department of Transportation on this demonstration project.

For this effort, VTTI partnered with Pronto, an ADS technology developer, to deploy their technology. Pronto has been at the forefront of the most important advances in the AV industry and is the only company to successfully drive coast-to-coast in the United States without a single driver input. In 2020, Pronto conducted testing at the Port of Oakland. They subsequently made refinements in their driving algorithms to account for cut-ins and aggressive driving behaviors. To better understand how the SAE Level 4 ADS-equipped vehicle would affect loading and unloading operations in port queuing settings, Pronto conducted a series of tests at the Oakland Ports to better understand the suitability of this technology in relieving major port congestion points in daily port operations.

For 4 months, Pronto developed and tuned their ADS platform to participate in daily port queueing activities at the Oakland ports. Initially, the ADS was already proficient at traversing the routes of the different queues but was unable to handle the speed and aggressive driving of other drivers. For example, as the queue progressed, any significant gap between the ADS-equipped vehicle and a leading truck would be a target for another driver cutting the line. In addition, if the ADS-equipped vehicle was driving too slowly or pausing when the queue started moving, it would be a target of aggressive honking and yelling by other drivers. For the ADS-equipped vehicle to be successful at participating in queue operations, Pronto spent most of the testing time tuning the system to be an effective driver under those circumstances. Key modifications to Pronto's base algorithms included reducing the transition time between the ADS being stationary and reinitiating motion when the queue resumed; improving the finesse of the ADS's adaptive cruise control to keep tighter gaps between leading vehicles; and improving object detection and tracking algorithms to prevent collisions during aggressive low-speed cut-ins.

To showcase the capabilities developed during those months, VTTI and Pronto set up a week of Port Queueing deployments where the ADS-equipped vehicle delivered at least one container a day for an entire week (5 days). The Pronto ADS operated flawlessly, negotiating heavy traffic and intersections. During the deployment, seven containers were delivered, 50–60 GB of data were generated (operating 2–3 hours each day), and each delivery was live streamed via Zoom to showcase the ADS capabilities to a wider audience at conferences as stated in Chapter 2.

3.2 CROSS-COUNTRY ROAD TRIPS

As part of the CONOPS project, the objective of the cross-country road trips is to demonstrate the application of ADS technology under typical fleet operations such as over-the-road operations, and especially to collect real-world data to understand how ready the existing roadway infrastructure across the United States is to support ADS technology. Drivers are often involved in long-haul operations that can include interstate travel under various roadway, weather, and time-of-day conditions. With such long driving hours, drivers are often fatigued and usually must take breaks over the course of the trips. ADS technology provides an opportunity to enable collaboration between human drivers and ADS such that ADS can take over the vehicle when drivers are fatigued (without having to stop the vehicle while resting) and within the ADS's ODD. This reduces the driving task load on the drivers, improves driving safety for drivers and other road users interacting with trucks, and allows the maximization of fleet resources since longer trips can now be assigned to drivers with the support of ADS. While these are the potential benefits of ADS-equipped trucks, the cross-country trips here focused on the first step towards future integration, i.e., assessing the existing roadway infrastructure to understand how they can support ADS. Hence, this part of the CONOPS collected roadway data related to lane marking quality, cellular connectivity, road conditions, and GPS connectivity. ADS-equipped trucks drove selected cross-country trips and collected information in real time over the course of these trips.

Five routes were selected for the cross-country trips. The routes were selected to ensure that the data obtained from the deployments can provide insights on infrastructure readiness and ADS performance on some of the most common driving conditions on U.S. roadways and can be used to measure the potential of ADS technology to serve fleet operations on these routes. The team also ensured the routes selected are often traversed by fleets, involved complex driving conditions (various terrains, times of day, weather conditions), covered interstate travel, and imitated over-the-road operations as often conducted by fleets. The trips covered States nationwide, thereby providing comprehensive data to measure infrastructure readiness and useful to stakeholders and decision-makers. Below are the routes.

- California to Texas, roundtrip
- Calgary, Canada, to California, one-way trip
- California to Florida, round trip
- Nationwide Cross-country Loop
- California – Oregon – Washington – Idaho – Montana – Wyoming – Utah – Arizona – Nevada – California

For these deployments, a number of ADS-equipped trucks, with similar ADS capabilities, were used. Although the trucks were capable of operating at Level 4 driving automation, safety operators were also onboard to take over at any point necessary during the trip. Hence, the deployments included both the ADS actively driving and the human drivers taking over when necessary. This ensured that the ADS operated within its ODD and control was transferred to the safety operator when not within the ODD. However, in both cases, vehicle sensors were actively collecting the data required to assess infrastructure readiness. The idea was to collect infrastructure data across these routes (whether ADS was active or not) and improve our understanding of how ready these routes are to support the deployment of ADS technology.

The trucks were retrofitted with sensors and high-performance computing technologies including high-definition cameras, front radars, six-axis inertial measurement units (IMUs), GPS, communication antennas, 8-core CPU + GPU, 4 terabyte storage devices, and a Controller Area Network (CAN) interface board. This enabled the collection of data, including encoded and timestamped video streams from cameras (including driver-facing), numerical data, positional data, vehicle motion data, radar cluster data, CAN data, and other high-level perception and planning information. Additionally, VTTI's proprietary data acquisition system (DAS), FlexDAS, was installed in all participating vehicles. This includes a core i7 CPU, support for high-definition USB cameras, onboard IMU and GPS, and data storage devices. The FlexDAS collected a wide range of data while remaining unobtrusive to participant drivers. As a sample use case, roadway readiness indicators (such as lane marking, GPS and cellular signals, and road bumpiness/smoothness) were obtained from these sensors and used to assess roadway infrastructure readiness for all roadway segments along the trip routes. A summary of the data use case is provided in the next paragraph and detailed in section 5.7. Further, safety performance indicators including traffic violations, near-crash events, and disengagements can be obtained from the data to assess the safety performance of ADS-equipped trucks (see section 5.6 for more) while the technology is active.

Section 5.7 details how some of the data obtained from these cross-country deployments have been used to develop a road readiness rating system for ADS technology. The rating system combined data from FHWA's Highway Performance Monitoring System (HPMS) database with data collected from the ADS-equipped trucks, including the ADS-detected real-time lane marking quality, cellular connectivity (i.e., signal strength), GPS connectivity (i.e., count of GPS), and road condition (i.e., bumpiness/smoothness). The assessment used the ADS data to provide a detailed evaluation of the lane marking quality (using a 0 to 10 scoring scale) on all the roadway segments traversed by the truck. Cellular strength (using percentages) and GPS counts on these segments were assessed, and each of these metrics was geolocated on a geographic information system (GIS)-based map to visualize the readiness of the roadways on these cross-country routes to support ADS technology.

3.3 FLEET INTEGRATION – WHITTIER, ALASKA

The introduction of automated heavy vehicles has the potential to revolutionize the transportation industry, offering unprecedented opportunities for freight efficiency and road user safety. As sensing technology advances and developers better understand the roadway system, integrating AVs into the industry becomes an increasingly attractive option. However, there are many implications for implementing ADS on public roadways or private yards. Implementing ADS at a fleet- or operations-level is a complex undertaking that requires careful planning, analysis, and data collection in defining the domain space and evaluating the impact automation has across all organizational levels.

The goal of this task was to thoroughly define the organizational elements as they exist at an operational level to better understand the implications of introducing ADS into an intermodal fleet operating heavy trucks for repetitive driving actions in a private yard. This goal was accomplished by collecting relevant observational and interview data and using those data to perform various task, risk, and organizational systems analyses. The objective for the approach is to establish a baseline evaluation of the organization at the operational level for future use in identifying the impacts of incorporating AVs. The analyses address both organization- and person-level elements and relate those across a macro cognitive model for human involvement within their tasks and roles.

3.3.1 Manual Truck Operations

3.3.1.1 Methods

Documentation Review: The research team was provided with a set of materials from the fleet describing the safety guidelines for all on-site personnel, as well as the training documentation for lift operators. These documents contained significant reference material to guide the research team's observations and questions while performing site walk-throughs and visits. The location of the site was in Whittier, Alaska.

Walk-through: The research team employed two distinct types of walk-throughs to collect data: a non-barge yard visit and an active barge video review. The non-barge yard visit took place during a period when a barge was not docked at the port in Whittier; therefore, there were fewer personnel in the yard, and work consisted of preparation for an active barge. The non-active barge visit allowed the team to gather contextual information, observe surrounding infrastructure, and interview personnel involved in the operations. The active barge video review involved reviewing recorded footage of a large barge off-load. The team closely examined barge operations, identified patterns, and extracted valuable data about various aspects of the process. By leveraging these two walk-throughs, the team aimed to gather comprehensive and complementary data that would contribute to a more holistic understanding of the research objectives.

Non-Active Barge Site Visit: During the non-active barge site visit, the research team viewed the location of important barge tasks during non-active hours and visited the yard office where the crew keeps their equipment. This effort provided the team with an overview of the layout of locations, as well as a general description of where activities would occur during active unloading periods. The walk-through provided the research team with an opportunity to observe performed tasks on-site as well as to interview personnel. Additionally, the site manager reviewed performance indicators around the yard, such as the number of picks off the barge per minute and the time taken for each trip.

Active Barge Activity Video Review: In addition to the site walk-through, the team viewed footage captured during the barge operations in the previous week. Management collects footage like this to review possible incidents or understand efficiency on the yard. The footage showed an aerial view of the yard facing the southwest corner near the crossing. The video supplemented the information the team gained from the site visit. During the site visit, the team saw where each high-traffic area was and the ideal movement of barge operations. However, the video illustrated more clearly how each of the vehicles, pedestrians, and cargo movement interacted. The aerial view and playback control allowed for an illustrative method of observing how inefficiencies can build up over time. Overall, the barge activity video helped the team build a mental model of the moving parts present during barge operations and served as good preparation for the on-ground observations.

Interviews: The research team performed nine employee interviews during the data collection period in Whittier. Interviews were semi-structured and primarily done in the field during active work. Participants included seven freight operator (FO) employees and included two truck drivers, three forklift operators, two maintenance workers, and one executive. Further, one safety driver and one engineer from an automation developer were interviewed.

On-Site Active Observation: The most valuable data collection came from observing active barge operations on-site. The team arrived on-site at 11:00 a.m. on April 20, 2023, as the barge and railroad crews arrived and observed operations for approximately 9 hours. It is important to note that during these observations, the weather was moderate with no ice or snow on the ground except the plowed piles left over from the previous week's storm. However, site personnel mentioned that inclement weather often impacts how efficiently barge operations work.

While the lifts were moving the empty containers and cargo brought in by the railroad, the team was positioned at the "crossing," or the narrow section of tracks separating the lower yard from the upper yard. During observations, the team had access to a radio channel used by lift operators so communications could also be noted. This vantage point allowed the team to understand how the lifts move across the yard, communicate with each other, and interact with the railcars while the crew waits for the rail to be pulled from the barge.

During the off-loading of both the barge railcars and containers, the team moved to a more central location midway between the stern ramp and the side ramp. This position gave a better view of how the lifts move on and off the barge to other locations around the yard. Additionally, this position was directly in front of where the trucks park while waiting to be loaded with a container. Therefore, the team had an excellent view of how the lifts interact with the truck during the off-load. Lastly, the team had the opportunity to ride along with the two truck drivers and one safety operator. The three team members each interviewed their respective driver and were able to learn what tasks the truck drivers are expected to complete during barge operations. Overall, the on-site active barge operations allowed the team to solidify what variables the trucks, lifts, and other personnel experience as part of the fast-paced barge off-load environment.

3.3.1.2 Sociotechnical System

Primary Organizations: The primary organizations working at the Whittier port are the FO and the State Operated Railroad Corporation (SORC). Our primary engagement was with the FO, the organization overseeing the barge operations at the Whittier port. The FO holds responsibility for various crucial components, including the barge, barge workers, shipment equipment, drayage trucks, lift equipment, lift operators, and overall logistics. All parts of the shipping process, up to but not including the transport of rail, are covered by the FO.

SORC is another crucial organization in the Whittier port activities. SORC is responsible for bringing empty containers and outgoing shipments to Whittier for the FO to handle, pulling rail from barges, setting up the rail for reloading, and transporting the bulk of the goods (~70%) out of Whittier to other locations in Alaska. Furthermore, the yard is owned by SORC, making them responsible for yard maintenance. Any snow removal or yard-related maintenance is at the discretion of the railroad.

One major difference between the SORC and the FO is the way workers are staffed for unloading barges. The FO employs a group of workers to live in Whittier on a rotating schedule of 4 days on and 3 days off. The FO employees have their room, board, and food covered while in Whittier and can earn unlimited overtime. SORC employees operate following government regulations and union contracts that prohibit working beyond 12 hours. The Rail Safety Improvement Act of 2008 provides strict guidelines for how often rail workers should be on and off duty.(1) Furthermore, rail workers commute to Whittier rather than living there for stretches of time.

The difference between the FO and SORC work culture can extend already long and challenging barge off-loading events. A barge needing 30 hours to unload, for example, will require three railroad crews. Three railroad crews mean potentially waiting for rail-critical actions, like setting up new lines of rail to be loaded with shipments, which may hold up the unloading process as staffing is found and crews shift in. In many cases, SORC crew shifts do not impact the barge unload, but in some cases, they can. The FO operators are trained to unload the barge quickly and safely. A tugboat can cost tens of thousands of dollars a day, so keeping tugboats from being held up can be essential.

Equipment:

- Trucks – The Whittier port activities rely on older trucks that have accumulated hundreds of thousands of miles. These trucks frequently require repairs to remain operational, with the exhaust system being one of the primary challenges. The trucks are primarily responsible for hauling substantial loads from the lower yard to the upper yard, making a low-speed, 1-mile loop. Transportation of heavy cargo within this distance is critical for the trucks' operations at the port. Nevertheless, low speeds and short distances do not allow Diesel Particle Filters (DPF) to regenerate efficiently. DPF regeneration occurs with either high-speed highway operations or driver/technician-activated periodic "burn-offs" of the DPF build-up to remain operational.

  Another challenge regarding the trucks used in Whittier is the difficulty of finding CDL drivers to operate them. The trucks observed were manual transmissions, requiring more knowledge to operate safely, and as equipped, could not be installed with ADS, which requires electronic gear control through automatic transmissions. Staffing for a weekly barge operation is difficult due to the short periods of operation and the unpredictable arrival of the barge each week. Finding experienced truck drivers to travel to Whittier for a variably arriving barge for an undisclosed amount of time can be difficult when truck drivers can make more consistent money transporting goods. Instead, the FO workers are expected to learn each role in the yard to be flexible in their placement based on the needs of the specific barge, including performing the job of a truck driver.

  The port operations currently use truck-tractors pulling double chassis trailer combination vehicles. In practice, this creates a longer vehicle for drivers to be cognizant of and a larger payload for each of the trucks to handle. More trucks with single chassis could fulfill the same cargo transportation requirements but would require more collective trips, would create more traffic in the yard, would require more staffing, and could create more maintenance needs.

- Lifts – Lifts play a vital role in facilitating the movement of shipments between the barge, railcars, and the yard. Due to the unique shape of the yard and the irregular shapes of some shipments received in Whittier, lifts are an essential tool in barge operations. The FO operators in Whittier primarily rely on fork and top pick lifts for barge operations. It is worth noting that various types of lifts exist, but these configurations are the key types utilized by the FO operators in Whittier.

The lifts used by the FO, at the time of this report, are Svetruck S1150s, which have several notable characteristics. First, the Svetrucks that FO operators use can carry 115,000 lbs. at once. Second, the two types of Svetrucks have different height lifting capabilities, with forklifts being able to stack containers up to five high and top picks being able to stack containers four high. Third, lifts do not have suspension in the way that passenger vehicles or freight trucks have suspension. Lifts have a three-point suspension system designed for carrying heavy loads to reduce the jostling of cargo.

- Railcars – The SORC manages all operations related to the railroad and owns the port where the FO operates. Optimally, the railcars used in the Whittier operation will arrive before or when the barge arrives. Once the railcars arrive, the FO lift operators work to remove and stage the empty containers and outgoing shipments from the railcars. The empties and outgoing shipments replace the now empty space on the barge and are subsequently sent to Seattle.

  The SORC has strict guidelines regarding the types and sizes of freight they accept for transport.(2) First, all shipments must conform to the current industry standards. Second, shipments must conform to one of the accepted sizes in the SORC load manual. The acceptable container lengths for rail shipments are 20, 24, 28, 40, 45, 48, and 53 feet. The acceptable platform lengths are 20, 24, 28, 40, and 53 feet. Rail cars can vary in size, but the primary sizes used in the Whittier operation are 89 feet and 56 feet.

- Barge – The main barge used in the Whittier shipping operation is a weekly vessel that starts its journey in Seattle. It typically takes around 8 days to reach Whittier, with the target arrival set for every Wednesday. These barges are 420-ft by 100-ft rail/container vessels designed to accommodate eight lines of rail and 32 rows of overhead storage.(3) It is important to note that the contents and organization of the barge change on a weekly basis.

  When the barge arrives in Whittier, the barge is docked and two ramps are set, one on the stern and one on the side of the barge. The stern ramp is where the rail is removed from the barge and lifts can access the port row of containers. The side (starboard) ramp is set after all of the rail is removed and gives lifts access to the starboard, port, and bow containers. See Figure 11 and Figure 12 for more information about barge layout.

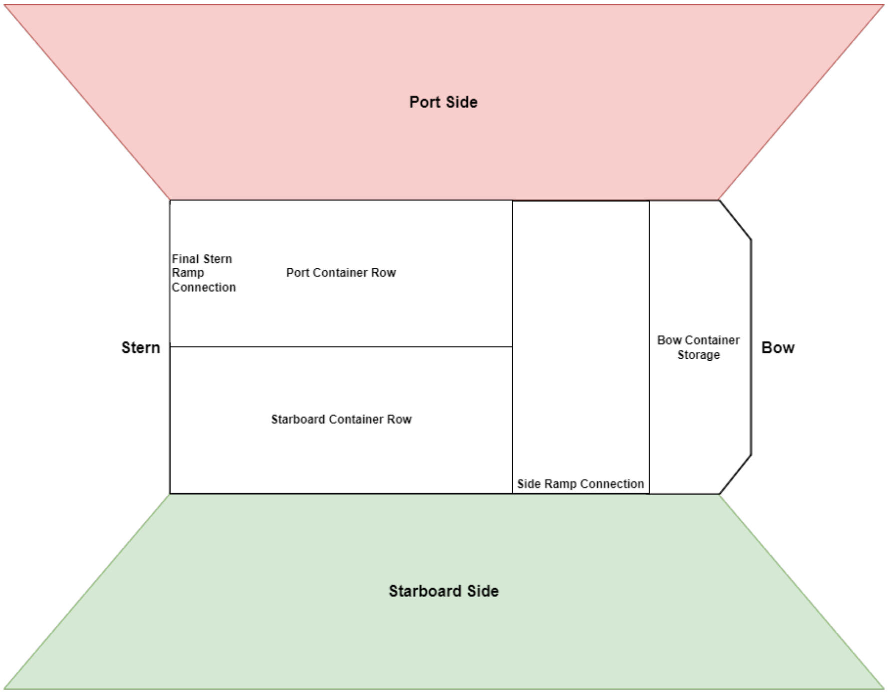

Figure 2. Diagram. A diagram of a barge with relevant locations labeled. The rail lines are located under the raised port and starboard container rows.

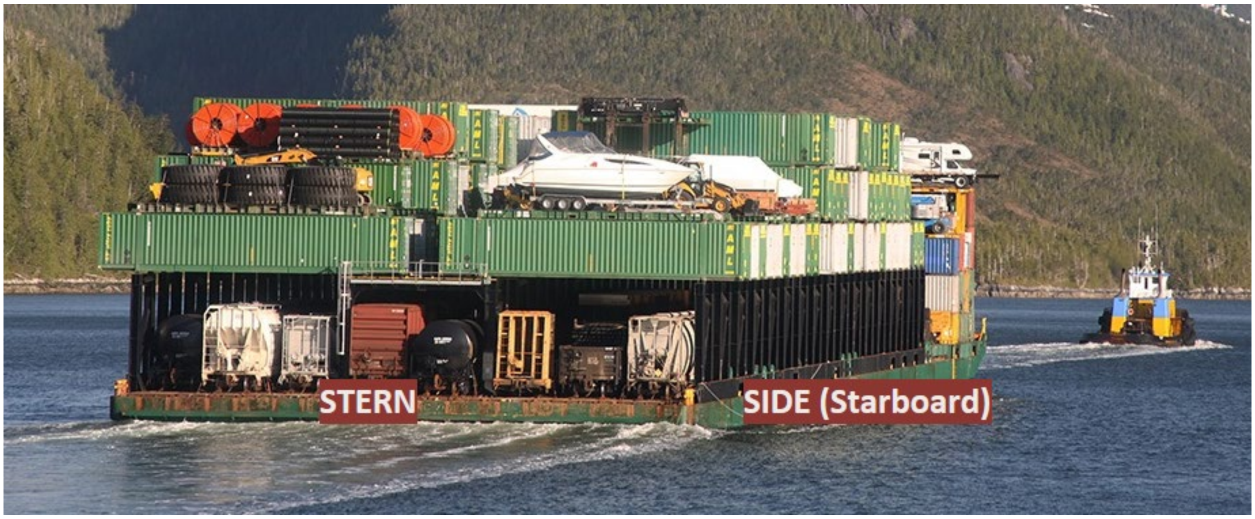

Figure 3. Photo. An image of a barge with the ramp connections labeled. (Source: Freight operator webpage.)

Location Description

Whittier is a port town with a population of 273, only accessible through a 2.5-mile, one-way, railroad-highway tunnel. Whittier is a prime shipping port for goods coming from Seattle by sea for several reasons: (1) To reach Anchorage by sea would take an extra two days; (2) Whittier is a deep-water and ice-free port; and (3) The town provides easy transportation through rail, road, or sea to Valdez, Anchorage, Cordova, and Fairbanks. Whittier provides a good location for receiving and sending shipments to the lower 48 States via Seattle. However, despite the location being ideal in terms of geography, the climate and port layout are essential to consider.

The climate in Whittier poses challenges for transporting barge shipments. While Whittier Port is one of Alaska's few year-round, ice-free ports, the combination of rain, wind, and snow throughout the year creates difficult working conditions for lift and rail operators. Whittier receives an annual precipitation of 196 inches of rain and 241 inches of snow, accompanied by winds commonly reaching 40–60 mph.(4) This situation leads to less-than-ideal snow storage locations, exacerbating the difficulties faced by workers and trucking operations.

The port layout in Whittier is also less than ideal. According to several lift operators, the ideal port for receiving shipments has ample acreage near the barge, has storage areas for containers, and minimizes distances that lifts need to travel. The Whittier port is narrow and long and has limited areas to store containers, which leads to long distances for lifts to move shipments to reach the train cars. According to Google Maps, a round trip from the barge to the train cars is approximately 1 mile. This round trip becomes problematic for lifts, as the extra driving distance increases exposure to risk for yard workers, increases lift tipping risk, increases the wear on lifts, increases the amount of time for barge unloading, and introduces an additional potential for shipment damage as lifts do not have shocks. More details regarding the port layout are given below in Figure 13.

Maps Data: Google, ©Airbus, CNES/Airbus, Maxar Technologies, Municipality of Anchorage

Figure 4. Map. A Google Maps capture of the Whittier Port yard with primary locations labeled. Green star = lower yard, green line = lower main track, red star = upper yard, red line closer to water = upper bay track, red line closer to bottom of picture = upper mountain, orange rectangle = the crossing. The ITB is the Integrated Tug/Barge where shipments for Cordova/Valdez are placed.

The Whittier Port yard is an area extending from east to west. Apart from the barges, the port can be divided into two primary areas: the lower yard (green) and the upper yard (red). Most lift operations occur in the lower yard, also known as the “Southside” among operators. The upper yard, sometimes called “Northside,” is where the train cars are loaded with Alaska-bound goods unloaded from the barge. Currently, the lower yard is utilized for loading trucks, specifically two double chassis trucks. The barge unloading process typically involves one forklift operator and two top-pick operators, although additional operators may be involved. Upper-yard operations usually consist of one top pick operator unloading the cargo transport trucks. During the observation of the operations, three top picks and two forklifts were present in the yard.

The upper and lower yard can be subdivided into specific areas based on the work performed. Within the upper yard, three notable locations exist: upper bay, upper mountain, and "no man's land." Upper bay refers to the rail line closer to the bay, while upper mountain designates the inland rail line. These locations are indicated as red lines in Figure 13. Approximately 70% of the cargo unloaded from barges is loaded onto these rail lines, heading westward out of Whittier. No man's land is the central area within the upper yard, between the upper bay and upper mountain rail lines. No man's land is a storage space for various items, including occasional snow accumulation, and creates a loop that cargo transport trucks must navigate to return to the lower yard.

In the lower yard, there are two specific locations where shipments bound for Alaska are sorted. The first is the Integrated Tug/Barge (ITB), a smaller barge transporting goods across Prince William Sound to Valdez and Cordova. The second location is the "lower main" line of rail. Although the ultimate destination may vary, the FO operators typically reserve this rail line for shipments heading to Fairbanks, Alaska.

The crossing is a section of recessed rail operators need to cross to transition between the upper and lower yards. The crossing is a critical junction in the yard where visibility is limited for truck and lift operators. Furthermore, when approaching the crossing from the lower yard, drivers are ascending a small incline, requiring trucks to increase their acceleration to get over the crossing when fully loaded. The crossing is colored in orange in Figure 13.

Primary Actors: Outside of the equipment and location, there are various actors and job roles that are essential for unloading a barge. The two primary groups working in the yard during a barge unloading are the FO and the SORC. Table 1 outlines the primary actors from each group present on the yard during operations.

Table 1. A list of the relevant actors related to unloading barges. The quantities and descriptions are those of a typically operating environment, not a hard and fast rule.

Actor	Quantity	Description	Organization
Forklift Operators	1	A forklift operator is typically the most experienced operator in the yard. A forklift can lift a wider variety of cargo, making their placement more important. Forklifts also require a higher skill level than top picks due to greater risk of dropping cargo off the forks.	FO
Top-pick operators	3	Typically, two in the lower yard unloading items from the barge and one in the upper yard transferring cargo from the trucks to train cars.	FO
Truck Drivers	2	These drivers may be lift operators who do not have a CDL. This is a hard position to fill with temps or part-time truck drivers, as the barge only comes weekly and the drivers would need to go to Whittier. Additionally, more money can be made with a CDL in other careers. The truck drivers drive in a loop from the side ramp to the upper yard and back.	FO
Yard Lead	1	Also known as the "person in charge," the yard lead manages the yard activities on the FO side. The yard lead watches for safety violations, manages efficiency, and makes operational calls.	FO

Actor	Quantity	Description	Organization
Maintenance	2	Maintenance personnel are on standby for any emergency repairs that may be required during operations.	FO
Barge Crew	# Set by Barge Manager	The crew that works on and arrives along with the barge.	FO
Safety Driver	1	In charge of the AV. Sets the vehicle path and manages system validation.	FO
Railroad Crew	# Set by SORC Manager	These are the railroad personnel responsible for rail-related operations, such as setting rail, pulling rail, and reorganizing rail. The railroad is also responsible for yard maintenance; e.g., snow removal. The yard typically sees two crew changes in one barge unload.	SORC

3.3.1.3 Activity Overview

To fully understand the interaction between the personnel, equipment, and processes during a barge off-load at Whitter, an overview of general operations is needed. The primary goal of the operation is to offload full containers from the barge onto the railcars to send off via train. There are subprocesses that support this goal. It is important to note that all railroad operations are handled by the SORC. The barge arrival time is tracked so that the SORC staff and outgoing railcars ideally arrive at the same time as the barge.

The first step in the process for the FO is to off-load the railcars entering Whittier from Anchorage. Empty containers and outgoing freight are removed from the railcars and stored at various places in the yard to allow incoming freight from the barge to be loaded onto the railcars. Simultaneously, the FO crew and barge operators work to secure the barge to the dock so SORC can begin removing the railcars from the barge. The rail cars need to be removed from the barge before any freight can be taken off by the lifts.

Once the railcars are clear to be reloaded with freight, the crew has a safety briefing. During this time, the SORC crew completely remove all the railcars from the barge. After the briefing and all railcars are removed, the forklift operator removes the barrier between the barge and the dock, then places and secures a ramp to allow the lifts access to the barge. Once the side and stern ramps are secure, the process of removing the freight from the barge begins. This freight is moved to various places around the yard, including the upper yard to load onto rail, the upper yard to load onto truck chasses, the ITB, rail for other destinations, on the yard for temporary placement, and the FO-based equipment for use or storage at Whittier. After the barge is fully off-loaded, the empty containers and outgoing shipments brought in by rail are backloaded to the barge returning to Seattle. Figure 14 illustrates this high-level workflow.

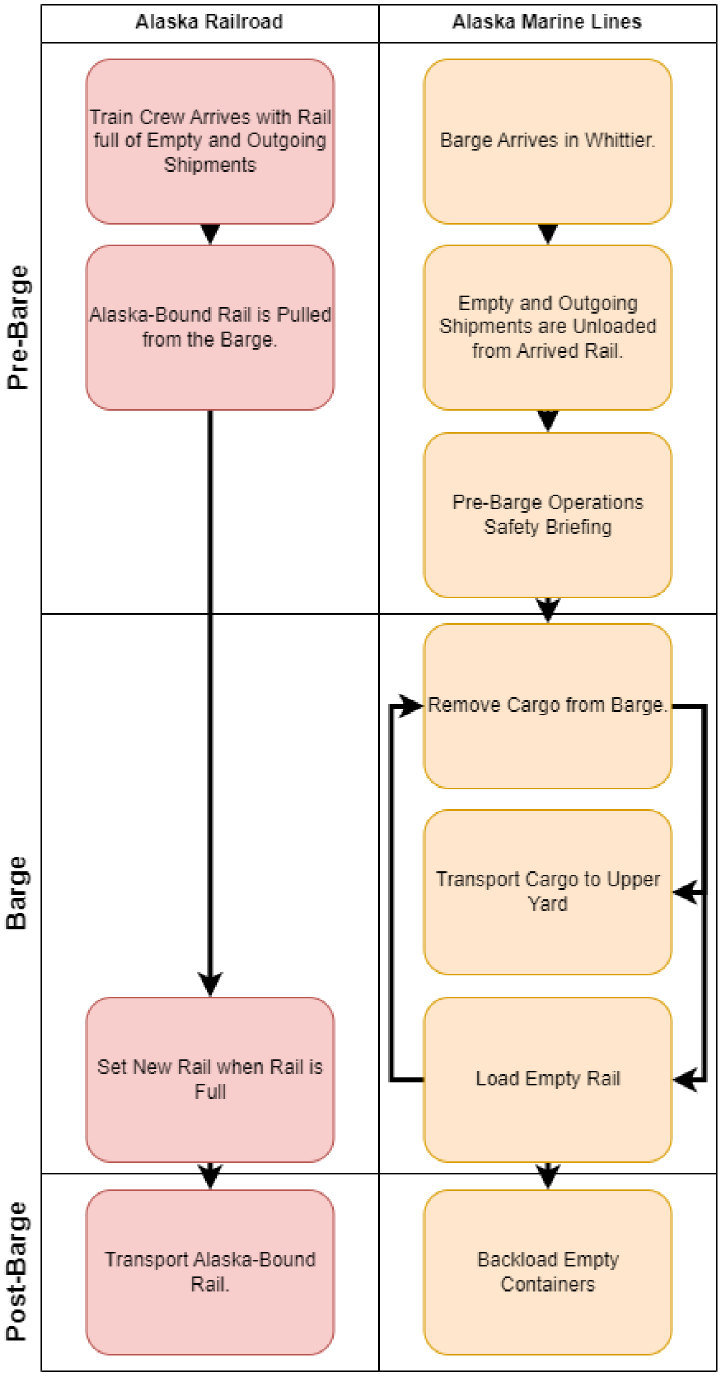

Figure 5. Diagram. A high-level workflow of the entire process from the barge's arrival in Whittier to before the barge's departure. The left lane pertains to the activities the SORC performs, and the right pertains to the activities the FO performs. Some activities, like the FO barge activities, are cyclical and repeat until all of the cargo is unloaded from the barge.

3.3.1.4 Detailed Activities

With Whittier being such a diverse port, there are many tasks completed simultaneously to support operations. The high-level workflow above represents many of these tasks; however, the main purpose of this analysis is to capture the tasks related to the trucks being used to move freight from the barge to the upper yard, which only represents a piece of these operations. Therefore, the following sections break down these higher-level tasks into pre-barge, barge, and post-barge activities, where only the truck-relevant tasks are described in greater detail.

Analysis Approach: Beyond capturing the workflow, the team also analyzed the workflow using an approach inspired by the macrocognitive perspective and Human Reliability Analysis (HRA).(5,6,7) The macrocognitive model was designed as a naturalistic model of cognition. Rather than focusing on finite components of cognition, macrocognition focuses on categories of processing and action that occur in real-life settings. The macrocognitive model breaks human processing into five major components: Detecting, Sensemaking, Decision-Making, Action, and Coordination. The macrocognitive components are interactive but independent components of the greater system of cognition. For example, detected objects can feed into decision-making, but do not need to.

HRA is another perspective infused into the analysis approach. HRA employs a concept called Performance Influencing Factors (PIFs) to help predict failure or human error (see Table 2). PIFs are contextual, circumstantial, organizational, and individual factors contributing to human performance.(8) For example, some common PIFs include task complexity, time pressure, attention, and stress.(9) While some PIFs are commonly found in diverse HRA methods, many methods are domain specific. Still, integrated frameworks attempting to generalize PIFs for HRA have been proposed.(10,11) See Table 2 for an example PIF table.

Table 2. Example PIF table adapted from reference 9. The PIFs captured in this table are combined from multiple HRA methods applied in the nuclear power industry.

Organization-based	Team-based	Person-based	Situation/stressor-based	Machine-based
Training program	Communication	Attention	External environment	Human-system interface
Availability	Availability	To task	Conditioning events	Input
Quality	Quality	To surroundings	Task load	Output
Corrective action program	Direct supervision	Physical and psychological abilities	Time load	System response
Availability	Leadership	Alertness	Other loads	
Quality	Team coordination	Fatigue	Non-task	
Other programs	Team cohesion	Impairment	Passive information	
Availability	Role awareness	Sensory limits	Task complexity	
Quality		Physical attributes	Cognitive	
Safety culture		Other	Execution	
Management activities		Knowledge/experience	Stress	
Staffing		Skills	Perceived situation	
Scheduling		Bias	Severity	

Organization-based	Team-based	Person-based	Situation/stressor-based	Machine-based
Workplace adequacy		Familiarity with situation	Urgency	
Resources		Morale/motivation/attitude	Perceived decision	
Procedures			Responsibility	
Availability			Impact	
Quality			Personal Plant	
Tools			Society	
Availability				
Quality				
Necessary Information				
Availability				
Quality				

The goal is not to include a full range of PIFs that can be applied in every circumstance related to barge unloading. Instead, the goal is to help identify many of the core factors that non-human factors professionals can apply. Furthermore, the tables we include in subsequent sections do not constitute a comprehensive list of all PIFs that can impact yard work but rather list some of the most crucial PIFs related to yard work. A PIF-oriented macrocognitive approach provides a detail-oriented and empirically backed method for understanding the threats to performance, no matter the task.

In the rest of this section, we explore each component of the approach we apply to analyze the workflows. First, we examine Detection, then Sensemaking, Decision-Making, Action, and Coordination. In each section, we define the cognitive process and then highlight threats to the successful completion of the process based on literature and expertise. Please note that the primary focus is to outline and analyze the tasks performed on the yard at the port in Whittier, and a full review of human performance factors is beyond the scope of the paper. The detailed analysis of the overall workflow will refer to the threats of completion highlighted for each process.

Detection: Detection includes the process of filtering an immense amount of information and noticing relevant stimuli in the environment.(12) In contrast with traditional cognitive psychology, detection in macrocognition includes sensation, attention, and perception while taking a more practical look at how people perform in complex environments outside of laboratories.(13) For example, a driver must sense, attend, and perceive a pedestrian to predict the pedestrian's behaviors and decide how to act. The yard where lift and truck operators work contains a host of moving objects and numerous threats to detection. Note that detection includes auditory, visual, and other modes of sensing the environment.

One aspect of failures that is important to note is that error likelihoods are extremely low.(14) Specifically, the likelihood of the individual not detecting a specific object, especially a relevant one, is quite low. Accidents and failures are a result of multiple failures in a system that compound on one another.(15,16) Table 3 lists potential threats to performance for detecting pertinent environmental information.

Table 3. Environmental, human, and object characteristics that impact a worker's ability to detect objects. The example risks are extracted from a combination of references 7, 10, and 11, manuals provided by the FO, and observation by human factors professionals.

Risks to Detection	Description
Ambient Noise	Background noise not related to the important information can interfere with picking up important auditory signals – e.g., a walkie-talkie chirp.
Attention	Inattention can lead to workers missing important information in their environment – e.g., a pedestrian in the yard.
Experience	Experience can inform where to focus attention, whereas inexperience can do the opposite.
Fatigue	Physical and/or mental weariness from the lack of rest, high-task demands, or overexertion can lead to poor object detection (lower attention capability).
Low Visibility	Low visibility, from fog or darkness, can reduce the likelihood of detecting a work or safety-relevant item in the environment.
Object Salience	How noticeable an object is may impact how likely someone is to detect the object. For example, safety vests increase salience by increasing luminance and using a bright color.
Occlusions	Obstructions in the yard can block operators from detecting relevant information in their surroundings – e.g., vehicles can block other vehicles from view.
Stress	Stress, caused by work or personal life, can create a lapse in attention and missed detections.
Workload	The more information a worker needs to process to complete their job, the more likely they are to miss relevant information in their environment.

Sensemaking: Sensemaking is the process of interpreting perceived information using experience and context to generate understanding of a situation.(17) In other words, sensemaking is making sense of our environment and building situation awareness. The process of sensemaking ranges from fast, automatic processing to slow, effortful thinking, and includes forming explanations, projecting future states, seeing relationships, and identifying problems.(18,19) Situation awareness and a good mental model of the yard state are paramount for yard operators to perform their job safely and efficiently. See Table 4 for more information about risks to sensemaking and how performance is impacted.

Table 4. Various characteristics that impact a worker's ability to make sense of their environment. The example risks are extracted from a combination of references 7, 10, and 11, manuals provided by the FO, and observations made by human factors professionals.

Risks to Sensemaking	Description
Attention	Attention to a task will increase an individual's ability to pick up on crucial information to make sense of their environment.
Experience	Experience helps yard workers know which information is relevant. This repeated exposure helps workers translate the complexity of yard work and can increase situational awareness.
Failed Detection	Workers can fail to make sense of a situation when critical information is lost during detection.
Fatigue	Physical and/or mental weariness decreases the ability to connect information and a good mental model of a situation.
Human-Machine Interface (HMI)	The design of the HMI can impact a worker's understanding of the system's states.
Incorrect Detection	Workers can fail to make sense of a situation when incorrect information is collected during detection.

Risks to Sensemaking	Description
Motivation	Low motivation can lead to poor use of contextual information and an inaccurate mental model.
Stress	Stress can reduce a worker's ability to focus on relevant information to make sense of their situation.
Training	Poor training can lead to a poor mental model of work and lead to inaccurate assumptions.
Trust	Low trust in other teammates can lead to reduced accuracy of contextually accurate mental models and situational awareness.
Workload	Increased cognitive resources to complete a task can reduce a worker's ability to unify contextual information and form a good mental model.

Decision-making: Decision-making is the cognitive process of choosing between different possibilities.(20) Despite the straightforward definition of decision-making, the cognitive process is complex. Decision-making can be quick and automatic or slow and resource intensive.(21) Decisions related to practiced activities tend to become more automatic and rely heavily on knowledge from previous experiences.(22) On the other hand, less exposure to a situation forces a greater reliance on the information absorbed from the environment, experience, and the ability of an individual to think through potential decision outcomes.(23) For yard operators, where information is constantly changing, decision-making can be impacted by various environmental and individual characteristics. Table 5 lists how different human and environmental characteristics can impact decision-making ability.

Table 5. Various characteristics that impact a worker's ability to make decisions. The example risks are extracted from a combination of references 7, 10, and 11, manuals provided by the FO, and observations made by human factors professionals.

Risks to Decision-making	Description
Expectation	A separation between reality and what an individual expects can lead to poor decision-making. The wrong mental model of a situation can lead to inaccurate application of rules and procedures.
Experience	Experience and the building of expertise can lead to more efficient and accurate decisions.
Fatigue	Mental and/or physical weariness has been found to negatively impact decision-making.
HMI	The design of alerts that provide workers with system information can impact the way decisions are made.
Incorrect Sensemaking	Misinterpreting a situation can lead to less efficient or incorrect decision-making.
Personality	Individual characteristics, such as impulse control, can impact decision-making ability.
Safety Culture	A poor safety culture can lead to less invested decision-making by workers, potentially reducing safety.
Stress	Stress can reduce the efficiency of decision-making when too much or too little is present. Both too little and too much stress can lead to poor performance.
Training	Lack of proper training can lead to an incorrect mental model of a situation, which can then lead to poor decisions.
Workload	Fewer cognitive resources can lead to poorer decision-making, as decision-making can require extensive cognitive resources.

Action: Action encompasses observable behaviors performed by an individual. Actions do not include the underlying cognition that led to the action but are limited to the execution of physical behavior.(24) For our purposes, this means the only errors falling into the category of action would be related to execution failures and would not include decisions leading to the action.(25,26) Reaching for one button but overshooting and hitting another or putting a vehicle in Reverse instead of Drive are good examples of execution errors. The intended action is performed incorrectly, no matter the correctness of the decision. Table 6 describes the impacts to the successful performance of actions.

Table 6. Various characteristics that impact a worker's ability to perform an action. The example risks are extracted from a combination of references 7, 10, and 11, manuals provided by Lynden, and observation made by human factors professionals.

Risks to Action	Description
Attention	Inattention can lead to inaccurate motor movements or slips of behavior.
Experience	The more experience someone has performing an action, the more automatic behaviors become. Inexperience can lead to less efficient and less successful behaviors.
Fatigue	Physical and/or mental weariness can lead to less efficient visual acuity, attentional capability, and motor accuracy.
Human-Machine Interface	A poorly designed interface can lead to poorly executed actions. For example, a poorly designed interface might not space buttons out appropriately and lead to mis-pressed buttons.
Road Conditions	Poor road conditions can include ice, potholes, or other contextually relevant factors. For example, slick roads can lead to poor traction, which can lead to poorly executed vehicle maneuvers.
Stress	Stress can create urgency in actions, potentially reducing accuracy.
Training	Lack of training can lead to less safe and more inefficient and ineffective actions.
Temperature	Colder temperatures, or bulky clothing due to temperature, can impact physical sensation and motor control, making actions more difficult to complete.
Vibration	Vibration can add variation to physical actions through repetitive physical movement. Vibration can also cause fatigue and physical stress.
Wind	Wind can be an issue for lift operators, as the wind can impact the stability of lifted containers, especially light and empty ones.
Weather	Weather conditions, including temperature, wind, and precipitation, can impact motor control and action execution.

Coordination: Coordination includes the processes related to people adjusting their behaviors to others in order to reach a common goal; this is similar to the Teamwork component in reference 7.(27,28) Coordination takes all of the other components in the macrocognitive process and places them in the context of teamwork, where work cannot be completed independently. Regarding a shipping yard, at least two trucks and five lift operators perform various duties around each other and must coordinate their movements to accomplish the common goal and avoid accidents or injuries. Communication, verbal and nonverbal, is critical for coordination efforts. See Table 7 for a list of risks to coordination performance.

Table 7. Various characteristics that impact a worker's ability to coordinate with others. The example risks are extracted from a combination of references 7, 10, and 11, manuals provided by the FO, and observations made by human factors professionals.

Risks to Coordination	Description
Attention	Lack of attention can increase the likelihood of missed visual and auditory communications. Inattention can also lead to poor situational awareness and therefore poor coordinated efforts.
Ambient Noise	Ambient sound can block auditory communications that are important for coordination.
Equipment Failure	Equipment failures on the yard can lead to unplanned reduction in manpower and access to work. Communication equipment failure can leave teammates without proper knowledge about the progress on the yard.
Experience	Experience can impact frequency and quality of communications as well as shape the forms of coordination.
Fatigue	Physical and/or mental weariness can lead to difficulty maintaining situational awareness and staying apprised of coordinated efforts.
Stress	Stress, internal or external, can create inattention, missed communication, and poor situational awareness.
Low Visibility	Low visibility reduces the ability for visual communication and situational awareness.
Role Awareness	Role awareness is important for workers to stay coordinated with others. Performing the correct duties at the correct time in relation to others is important for group work.
Safety Culture	Safety culture can impact the way workers take risks around other workers in the yard.
Training	Poor training can lead to a poor mental model of work in the yard and potential errors. For example, determining who has the right-of-way in relation to trucks, pedestrians, and lifts.
Workload	Higher workloads can lead to a reduced ability to stay engaged with relevant information to stay coordinated with others.

3.3.1.5 Macrocognition Examples in the Workflow

The following sections are broken into three major categories to provide specific examples for each of the barge tasks. First, we discuss everything that occurs before the barge unloading takes place, up to and including the setting of the side ramp. Second, the unloading of the barge is discussed. Finally, we discuss the post-barge activities, or the work occurring after the barge is unloaded. The analyses are limited to examining the FO employees, primarily the truck and lift operators. While SORC operations are critical for successful yard and barge operations, the primary goal is to capture the interactions between the trucks and lifts. Each section details specific instances of the risks to macro-cognitive processes pertaining to barge activities.

Pre-Barge: Before unloading the barge, the FO and the SORC must complete several tasks. While workflow information pertaining to the inbound rail being pulled from the barge by SORC, the pre-barge operations safety briefing, and the setting of the side ramp are included in the pre-barge tasks, the focus for pre-barge activities is the unloading of empty containers and outgoing shipments from the rail brought in by the SORC. In other words, the work done by the FO lift and truck operators working in the yard are the focus of the pre-barge tasks.

Pre-barge activities rely on several moving parts to operate smoothly. First, the arrival time of the barge is highly dependent on the weather patterns and can vary greatly. Second, the arrival time of SORC impacts the timing of almost all the other work in the yard. The SORC arrives in Whittier with empty containers and outgoing shipments that must be unloaded into the yard or loaded onto the barge. The rail SORC arrives with is the same rail that the FO loads for shipments coming into Alaska from the barge. The ideal timing is for the barge and SORC to arrive around the same time so that the rail can be pulled from the barge as the FO empties the arrived rail.

Rail Is Pulled from Barge: SORC pulling the incoming rail from the barge is a critical step in the pre-barge activities. The barge arriving in Whittier from Seattle typically has eight lines of rail that need to be removed before the FO can start unloading cargo with lifts. The removal of the rail can take several hours (3 hours during our observations). During this time, the FO is unloading the empty containers, and outgoing shipments from the SORC into Whittier.

Pulling the rail from the barge is an involved process. Once the barge arrives, the barge crew from the FO sets to work on unlocking the rail from the barge. As each line of rail is unlocked, SORC uses winches to push and pull the barge so that the unlocked portion of the rail on the barge lines up with the rail on the stern ramp. Once the rail is aligned, a locomotive is attached, and the rail is pulled from the barge. The process of aligning the rail, attaching the rail to a locomotive, and pulling the rail off the barge is repeated until all the rail has been removed. See Figure 15 for a diagram of the process.

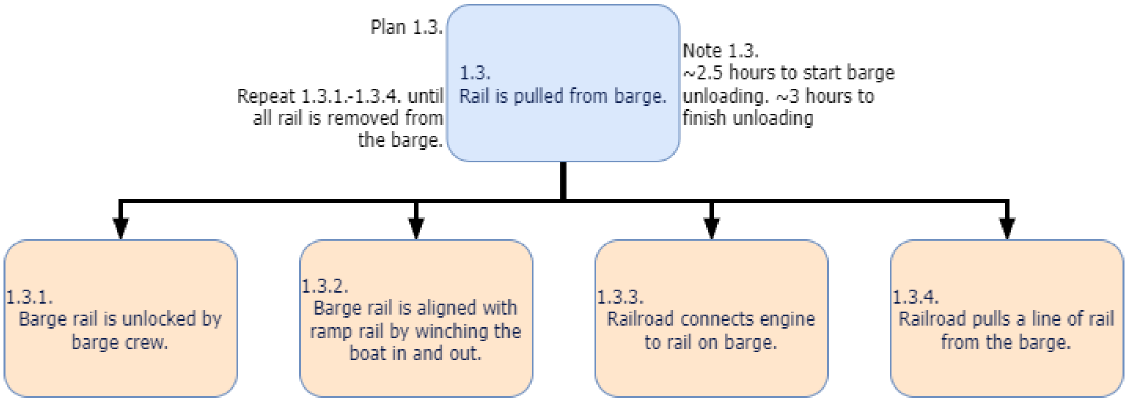

Figure 6. Diagram. A high-level hierarchical task analysis of rail being pulled from the barge.

Before any other cargo can be removed from the barge, all the rail needs to be removed. This step typically happens concurrently with the FO removing the empty and outgoing containers from the rail brought to Whittier by SORC. Any delay in the pulling of rail from the barge can delay the rest of the process and, depending on the speed of the lift and truck operators in removing the containers from the rail, can lead to significant downtime for the FO yard operators. This potentially compounds fatigue occurring during the barge unload.

Empty and Outgoing Containers Are Unloaded from Rail: Once SORC has arrived with the outgoing shipments and empty containers on the rail, the FO lift team can begin removing containers from the rail. Typically, lift operators remove containers from the rail and place them in various staging areas in the yard. This process relies heavily on experience, understanding the cargo's final destination, and knowledge of the barge unloading procedure. For example, empty containers may be placed in an area of the yard that is unused during barge unloads but close enough to the barge where, if the empty containers are being backloaded (loaded onto the barge after incoming cargo is removed), they are easy to access. At the same time, outgoing shipments need to be stacked in specific ways to avoid damaging any containers or causing any interactions between the contents of the containers, but also so that they are out of the way for other operations. This procedure is performed by top pick and forklift operators; no trucks are involved in this process. See Figure 16 for a workflow diagram of the entire process.

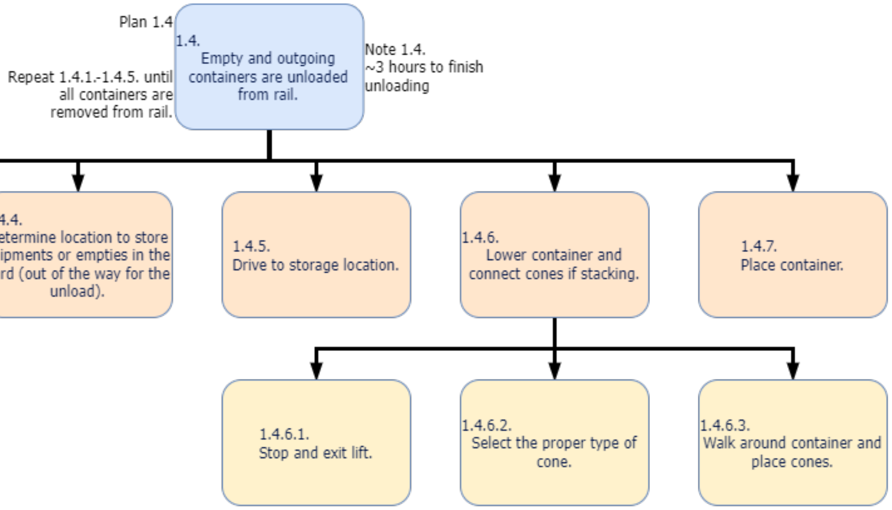

Figure 7. Diagram. A high-level hierarchical task analysis of unloading the empty and outgoing containers from rail. This task is completed by lift operators.

Removing empty and outgoing containers from the arrived rail is critical to the efficient operations of later barge activities. While off-loading the arrived rail is straightforward and occurs early in the lift operator's workday, experience is an operator's friend. Where to place the cargo in the yard, the proper procedures for stacking containers safely, and clear communication are all critical for safe operations. In the following sections, we will assess the macrocognitive levels associated with off-loading the arrived rail and preparing the yard for off-loading the barge. Example risks for each macrocognitive level will be discussed.

Macrocognition and Unloading Empty and Outgoing Containers from Rail: Detection is a fleeting but critical safety component and occurs repetitively throughout all the subtasks identified for unloading empty and outgoing shipments from rail (see Figure 16). Anytime an operator interacts with their environment, detecting relevant information is critical. While driving, an operator needs to be aware of pedestrians, other vehicles, road conditions, equipment state, and debris in the yard that could become dangerous. While lifting containers, operators must detect connection points for their lift, cargo placards, pedestrians, and other vehicles nearby. Detection is constant.

There are various risks to detection, as outlined in Table 3, and all are pertinent. Fatigue can serve as one example. Since the off-loading of the incoming rail occurs early relative to the scope of barge-related activities, work-related fatigue is less of a contributing factor to detecting safety or job-critical objects in the yard. However, non-work-related fatigue can still detrimentally impact detection ability. For example, if a barge arrives at 2:00 a.m. and operators are not used to working at that time, fatigue due to poor sleep could contribute to less competent detection. Object salience could provide another example. The salience of objects can serve as a second example. Pedestrians walking through the yard need to make themselves as visible as possible by using reflective safety gear and appropriate lighting for the conditions. Vehicles driving in the yard are expected to use a flashing beacon. Missing safety gear on vehicles or pedestrians and poor lighting conditions can reduce the likelihood of detection by lift operators. On top of that, detection can be challenging for lift operators because of the poor field of view available from lifts. Different locations in the yard will have different environmental hazards and threats to object detection.

Sensemaking is relevant for any detected object, but our analysis will focus specifically on the subtasks outlined in Figure 16. Sensemaking is especially relevant for choosing what containers to unload, determining where to store shipments and containers in the yard, and connecting cones if stacking cargo. While all the risks to sensemaking from Table 4 are relevant, experience and training are especially relevant here. Knowing what containers to remove from the train and where to put them requires understanding the barge unloading procedure, knowing the accessible areas in the yard, and having an accurate mental model of other operators' work. Training can bridge this gap, but experience is required for the most efficient and accurate understanding of where to store cargo. The same is true for knowing which stacking cones to use and where to place them on cargo if stacking in the yard.

Decision-making is most relevant for choosing containers to unload and determining where to store them in the yard. While sensemaking focuses on the understanding of the most efficient objects to take and understanding where they can go, decision-making focuses on the actual end choice made. Some relevant examples of risks to decision-making from Table 5 are experience and stress. Experience, like in sensemaking, can help guide operators to the best choice of location for storing empties or outgoing shipments. Communication and training may be able to make up for lower levels of experience, but less experience can lead to less efficient decisions. Stress, on the other hand, can create a sense of time urgency, where choice of cargo to take from the train and storage location can be less than optimal for backloading.

Action, like detection, is a constantly applied aspect of the macrocognitive approach. Actions are being taken for all subtasks, except choosing containers and determining where to place them, as identified in Figure 16. Some relevant examples of risks to action execution from Table 6 include weather and fatigue. During icy conditions, forklift operators need to be cognizant that their load does not slip off their forks. This is especially true when roads might be slick, and fatigue slows their reaction time. If a forklift operator were to slam on their brakes while driving over the crossing to the lower yard because of an oncoming vehicle, their cargo could slip off their forks.

Coordination is an overarching issue that permeates all tasks. All subtasks identified for unloading empty and outgoing containers from the rail include working around and with others. Some relevant examples of risks to coordination from Table 7 include training, role awareness, and visibility. Training can help give lift operators a sense of what vehicles have the right of way, how to drive around other operators, and how to communicate with other operators. However, low visibility can impact the ability of operators to communicate and predict each other's behaviors nonverbally. For example, another lift operator making eye contact can be a powerful cue of mutual awareness. Role awareness can also help direct other actions like knowing what objects the forklift operator needs to handle.

Pre-Barge Operations Safety Briefing: Prior to barge operations, the FO personnel involved in the off-loading meet to perform a safety briefing. The briefing is an important safety precaution to ensure all team members know what to expect during the off-loading. The team discusses any difficult cargo or known hazards that may be present, identifies possible unsafe conditions such as weather, and ensures that the person in charge (PIC) is clearly identified. The team also checks personal protective equipment, communication devices, and safety barriers. See Figure 17 for more information on the workflow.

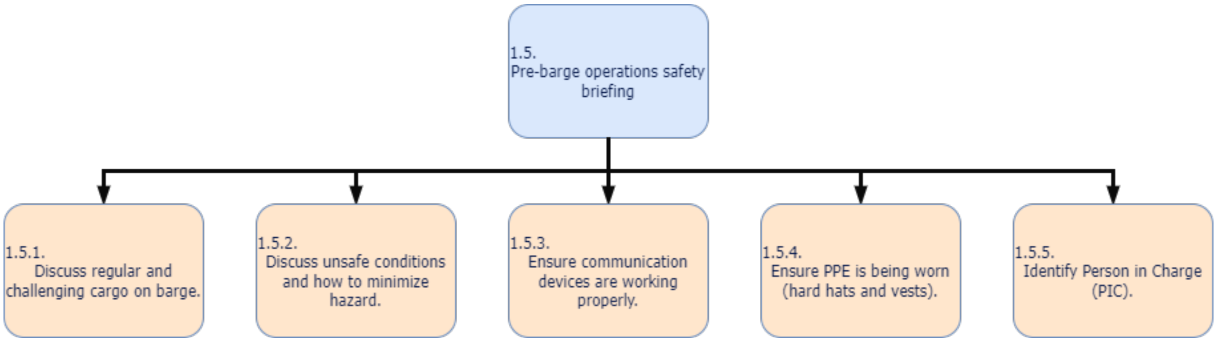

Figure 8. Diagram. A high-level hierarchical task analysis of pre-barge operations safety briefing.

The safety briefing is an important time to review best practices in order to prevent errors caused by complacency. Additionally, the safety briefing allows the yard manager to highlight any potential hazards in the yard, such as new potholes or poor visibility due to weather. Lastly, based on interviews with the lift operators, most operators rely heavily on experience to guide their decisions. Therefore, these safety briefings give more experienced operators time to guide newer employees.

The safety briefing acts as a barrier to safety incidents, improves efficiency, and sets an expectation of safety before operations. However, while the overall impact of the safety briefing is likely positive, something to consider is the amount of information communicated. An overload of new information can cause an additional mental load on less experienced operators. Less experienced operators are already coping with additional load, as they are performing their duties with less exposure to typical yard operations. For example, a newer employee may be so focused on properly tilting their lift while driving around three other operators in the yard that they forget about a pothole discussed during the safety briefing. On the other hand, more experienced employees are more likely to absorb and apply more of the information passed on in a safety briefing. This is not to say that safety briefings are a problem or should omit crucial information but rather serves as a reminder that it is good to be aware that holding onto new information is difficult while performing an unfamiliar task. The safety briefing is a critical component of safe yard operations.

Forklift Operator Sets Side Ramp: During the rail off-load process, the barge is moved a considerable distance, via winches, from the edge of the side dock. This leaves a large gap between the boat and the dock where equipment or personnel could easily fall into the water below. To prevent accidents like this, a large, metal frame barricade is placed between the edge of the dock and the side ramp.

After the SORC crew communicates to the FO crew that all of the rail is off-loaded from the barge and the team has their safety meeting, the forklift operator performs an action called “setting the side ramp,” where the operator moves the frame barricade out of the path and pushes the side ramp up against the side of the barge so the lifts can begin off-loading cargo. Setting the side ramp typically happens very early in the operation where, ideally, the effects of fatigue and vigilance decrement have not set in. However, the simplicity of this task may leave the forklift operator vulnerable to complacency, as the operator must remain vigilant to possible hazards while carrying the heavy barricade. Still, there is an extremely low likelihood that this step could go wrong. The completion of this step marks the end of pre-barge operations, and the activity now transitions to barge operations.

Barge: The barge activities begin once the lift operators can begin removing cargo from the barge and end after the last container is removed. The three main components of barge activities are removing the cargo from the barge, transporting the cargo to the designated yard location, and placing the cargo in the designated yard location. These activities occur cyclically for each cargo item removed from the barge.

There are several locations that cargo can be brought to depending on the eventual destination. Generally, cargo can be delivered to the upper yard rail, the lower yard rail, and the ITB. The ITB cargo is always reserved for cargo delivered to the cities of Cordova and Valdez in Alaska. The other locations can be designated for delivery to other parts of Alaska, such as Fairbanks or

Anchorage. About 70% of the containers are delivered to the upper yard on the rail, which is called the “Upper Bay Track.” See the map in Figure 13 for a better idea of the yard layout.

Remove Cargo from Barge: After the side ramp is set and the forklift operator removes the barrier, the lift operators begin removing the cargo from the barge. There are two main access points on the barge where lift operators can remove cargo: the side ramp and the stern ramp. The stern ramp provides access to the portside row of containers, whereas the side ramp provides access to both rows of containers and the bow containers. Lift operators choose the ramp they will use to access the cargo based on the cargo availability for their lift types, the cargo’s end location, and congestion in the yard and on the barge. Typically, there are four lifts in the yard: two top picks unloading the barge, one top pick unloading the trucks in the upper yard, and one forklift floating between locations based on non-pickable cargo. See Figure 18 for a more detailed task description of removing the cargo from the barge.

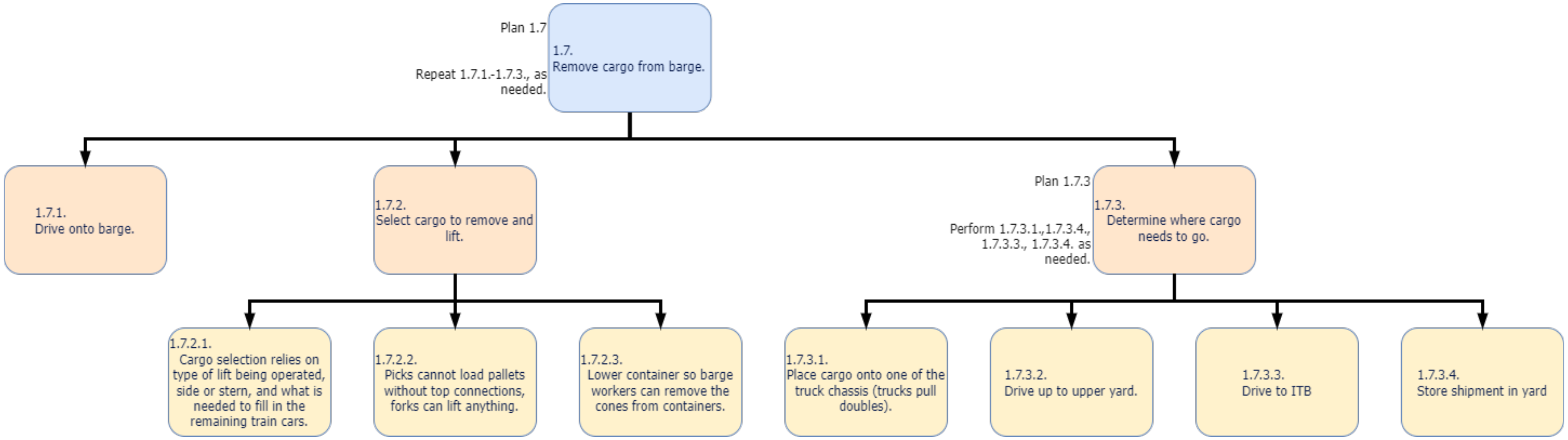

Figure 9. Diagram. A high-level hierarchical task analysis of removing the cargo from the barge. Note: task 1.7.3 can be broken down significantly more but was trimmed for space. This task is primarily done by lift operators, but trucks can be a core component of 1.7.3.

There are several notable aspects of barge unloading. First, the forklift operator is typically the most experienced lift operator on duty because this is the only type of lift that can move irregular cargo. Whenever non-pickable cargo is accessible on the barge, the forklift operator tries to move the cargo to avoid blocking any work the top picks can handle. The added responsibility can lead to forklift operators frequently moving between different locations in the yard. The forklift can also be more challenging to operate, as the metal forks can become slippery with ice, making carrying objects more difficult in inclement weather.

Second, the lift operators must make various decisions based on the location of other lifts, the types of cargo available for unloading, the locations to which the cargo needs to be brought, and the availability of trucks. If the cargo must go to the ITB or the lower main rail (see Figure 13 for a map), the lift operator will drive the cargo without the trucks. If the cargo needs to go to the upper yard, the lift operators will try to place the cargo on one of the trucks if one is available. If a truck is not available, the lift operator may drive the cargo to the upper yard themselves, which can be inefficient and may damage the cargo.

Third, lift operators must perform their work with poor visibility, a high mental load, and a complex environment with pedestrians and vehicles moving around them. First, lifts do not provide operators with great visibility, which only worsens when carrying cargo. Second, lift operators must be cognizant of how loads and the weather impact their lift's dynamics. A lift operator must be exceedingly careful to prevent their lift from becoming unstable due to their load, how high their load is lifted, the wind, and the terrain. Finally, lift operators must be aware of other vehicles and pedestrians moving through the yard. Two locations where this is especially true are on the barge and at the crossing. On the barge, pedestrian workers remove cones from cargo and keep the barge surface clean of debris. At the crossing, limited visibility can lead to collisions with trucks or other lifts if the operator is not careful.

The rest of this section focuses on a more detailed macrocognitive analysis of the "Remove Cargo from Barge" task.

Macrocognition and Removing the Cargo from the Barge: Detection is a fleeting but critical safety component and occurs repetitively throughout all the subtasks identified for removing cargo from the barge (see Figure 18). Some relevant example risks to detection from Figure 18 are attention and occlusions. For example, while driving onto the barge, attention to the various workers who may be moving around the barge is critical to avoid injury. Along with attention, experience using a lift and compensating for the visual occlusions caused by the lift structure can also be critical in avoiding an accident.

Sensemaking is primarily relevant for driving onto the barge, selecting the cargo to remove from the barge, and determining where to go with the cargo. Some relevant examples of risks to sensemaking from Table 4 are attention and experience. First, understanding which ramp to use to access the barge cargo requires the operator's attention to keep an accurate mental model of the current state of the barge. A mixture of experience and attentiveness is required for the appropriate level of situational awareness. Second, knowing what containers to remove from the barge and where to put them requires knowledge of the container destination, knowing where containers for each destination are brought in the yard, and having an accurate mental model of other operators' work.

Decision-making is also relevant for all three second-level subtasks. While sensemaking focuses on understanding, decision-making focuses on the actual end choice someone makes. Some relevant examples of risks to decision-making from Table 5 are experience and workload. When driving onto the barge, lift operators must consider the type of lift they are driving and what type of cargo is available to remove. A high workload can impact an operator's ability to keep the types of loads available on each side of the barge and may lead to inefficient decisions about where to best access the barge. More experienced operators can better handle higher workloads and will likely position themselves better for unload procedures.

Action, like detection, is a constantly applied aspect of the macrocognitive approach. Actions are being taken for all subtasks identified in Figure 18. Some relevant examples of risks to action execution from Table 6 include road conditions and experience. While driving in the yard, lift operators need to be cognizant of the road conditions and how angles can impact their lift's center of gravity. Typical actions can lead to accidents due to potholes and hills. Experience can offset the impact of poor road conditions, as more experienced operators will change their actions to fit the environment more accurately than less experienced operators.

Coordination for the barge unload is similar to the rail unloading. All subtasks identified for unloading the barge include working around and with others. Some relevant examples of risks to coordination from Table 7 include training, role awareness, and visibility. Training can help give lift operators a sense of what vehicles have the right of way, how to drive around other operators, and how to communicate with other operators. However, low visibility can impact the ability of operators to communicate and predict one another's behaviors nonverbally. For example, a barge worker making eye contact with a lift operator while taking cones out of their cargo can communicate mutual awareness. Role awareness can also help direct other actions like knowing that lifts always have the right-of-way.

Transport Cargo via Truck: Trucks have a primary role in transporting goods to the upper yard. Truck operators park in the lower yard between the stern and side ramps, waiting to be loaded with cargo designated for the upper yard rail. Depending on the lift operators' needs, truck operators may adjust their parking location to accommodate more cargo coming from one of the ramps. For example, if the side ramp has several pieces of cargo designated for the upper yard, the lift operators might signal the trucks to pull closer to their location for more efficient loading. After being loaded, the truck driver drives to the upper yard and waits to be unloaded by a lift operator. See Figure 19 for a breakdown of this task.

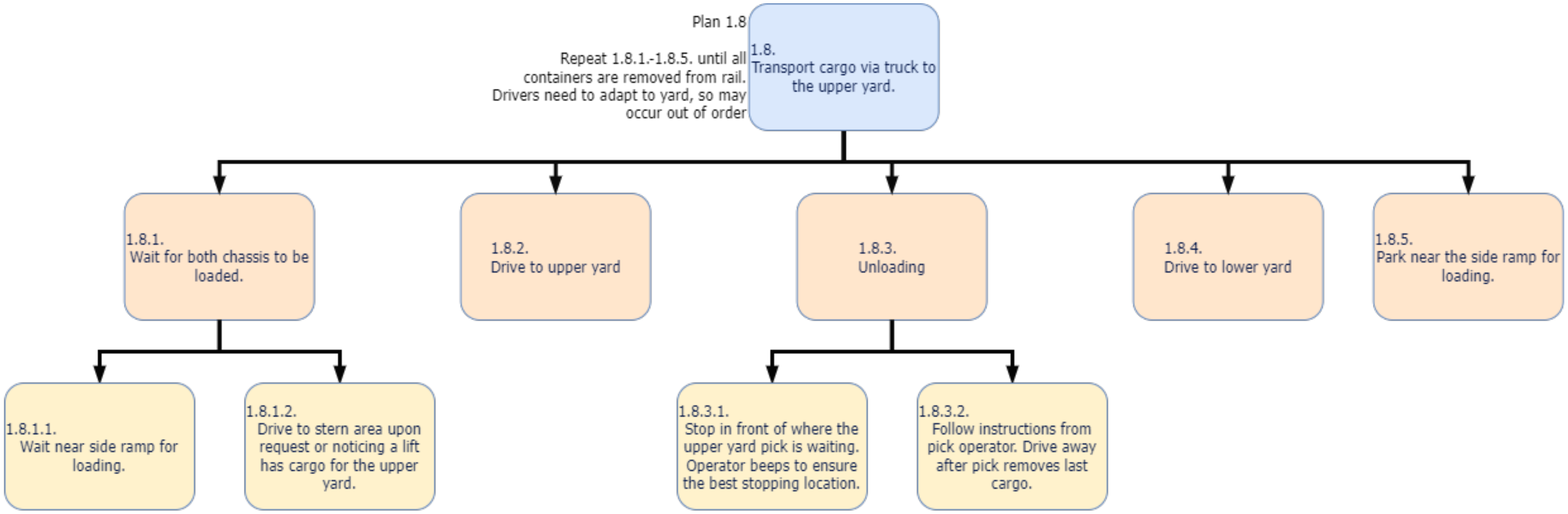

Figure 10. Diagram. A high-level hierarchical task analysis of transporting cargo to the upper yard via trucks. Primarily performed by truck operators.

Transporting goods from the lower to the upper yard via trucks involves several notable factors. First, the trucks are limited to 10 mph while driving through the yard. However, there is a general understanding that drivers need to vary their speed based on the environment. For example, when the road surface is slick due to weather, drivers need to accelerate and let go of the gas to overcome the incline at the crossing from the lower yard when fully loaded. Second, the crossing is a narrow location in the yard with potentially limited visibility. Great care needs to be taken when traversing the crossing. Third, the trucks are currently running double-trailer chassis.

Finally, when unloading, the truck driver stops in line with the lift operator in the upper yard or stops when they hear the lift operator's horn. The lift operator in the upper yard has to organize where each bit of cargo is being placed on the rail and tries to minimize their travel between the truck and the rail. The remainder of this section examines the transportation task through a detailed macrocognitive approach.

Macrocognition and Transportation of Cargo via Trucks: Detection is a fleeting but critical safety component and occurs repetitively throughout all the subtasks identified for transportation of cargo to the upper yard via trucks (see Figure 19). Some relevant example risks to detection from Table 3 are attention and ambient noise. For example, when the upper yard lift operator wants the truck driver to stop their vehicle, they honk their horn exactly where they want the truck to stop. If a truck driver is not paying attention, they may not detect the honk and park in a less efficient spot for the lift operator to transfer the cargo from the truck chassis to the rail. In addition to attention, fatigue can impact the reaction time to detecting the truck driver's horn. Ambient sound can also serve as a mask to the honk.

Sensemaking is primarily relevant for getting the truck chassis loaded, the unloading of their chassis in the upper yard, and parking near the side ramp. Some relevant examples of risks to sensemaking from Table 4 are attention and experience. First, truck drivers need to be paying attention to know where to place their vehicle near the barge to have their chassis loaded. Looking for visual signals or listening for a radio call can help the truck driver determine if they need to be closer to the side or stern ramp. Experience can also play a big part in this, as more experienced drivers will be able to keep an accurate mental model of the state of the barge better than inexperienced drivers; the same goes for knowing where to stop in the upper yard to be unloaded. Experience and attention can both help a driver determine where they need to be to best serve the lift operator.

Decision-making is mainly relevant for the same tasks as sensemaking. While sensemaking focuses on understanding, decision-making focuses on the actual end choice someone makes. Some relevant examples of risks to decision-making from Table 5 are experience and workload. When a driver parks the truck to be loaded or unloaded, more experience can help determine the best place to be to serve each operator. High workloads or inexperience driving trucks can lead to less efficient placement. Training may help alleviate the difference in performance as drivers learn where best to park.

Action, like detection, is a constantly applied aspect of the macrocognitive approach. Actions are taken for all subtasks identified in Figure 19. Some relevant examples of risks to action execution from Table 6 include road conditions and attention. While driving in the yard, truck drivers need to be cognizant of how road conditions impact their load and speed. For example, more experienced operators will know that to get over the crossing from the lower yard with a fully loaded double chassis in icy conditions requires accelerating into the incline and releasing the gas as they go over the crossing. If they do not accelerate or let go of the gas, drivers' risk not being able to get over the crossing or sliding into the Upper Mountain rail. Attention to road conditions is paramount to knowing how behavior needs to change.

Coordination for transporting cargo in the yard via truck is similar to other coordination tasks in the yard. All subtasks identified for unloading the barge include working around and with others. Some relevant examples of risks to coordination from Table 7 include training and role awareness. Training can help truck drivers better understand the equipment, what vehicles have the right of way, how to drive around other operators, and how to communicate with other operators. As a side note, as previously noted, few truck drivers in the yard have a CDL or have been formerly trained to drive trucks as they operate in a private yard, and formerly trained truck drivers are difficult to staff. Role awareness can also help direct other actions, like knowing that lifts always have the right-of-way in the yard.

Load Train: Loading the empty rail in the upper yard links well with the previous task, "Transport Cargo via Truck". After the truck arrives in the upper yard, the lift operator needs to assess the state of the rail, determine what kind of cargo the truck is transporting, decide where the cargo needs to be placed on the empty rail, tell the truck driver where to stop (through a horn or radio call), lift the cargo from the truck, transport the cargo to the train, and place the cargo. Choosing the correct location for the cargo is a crucial part of the upper yard activities. Early mistakes in placement can lead to less efficiency as the barge unloading continues. Sometimes, the upper yard lift operator will help unload cargo from the barge early in the unload and will only move up to the upper yard when needed. See Figure 20 for more detail on this task. The rest of this section examines the process of "Load Train" in more detail.

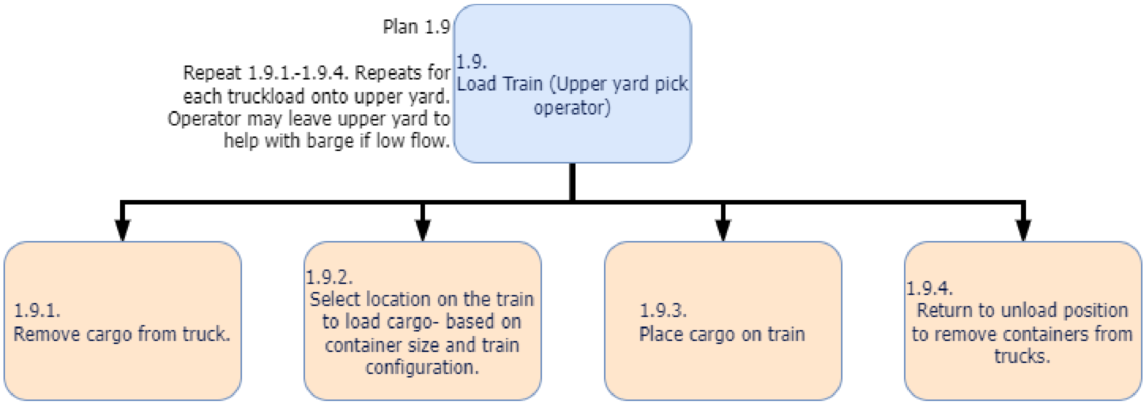

Figure 11. Diagram. A high-level hierarchical task analysis of loading the train with incoming shipments. A combination of lift and truck operators.

Macrocognition and Loading the Train: Detection is a fleeting but critical safety component and occurs repetitively throughout all the subtasks identified for loading the train in the upper yard (see Figure 20). Some relevant examples of risks to detection from Table 3 are stress and fatigue. Little other traffic outside of trucks is present in the upper yard. High stress and fatigue can work independently or together to prevent detection of pedestrians or to prevent other unexpected vehicles from being detected. Stress and fatigue can also impact the detection of leftover cones in cargo crates. Cones are not particularly salient objects, and fatigue can quickly reduce the likelihood of noticing them.

Sensemaking is mainly relevant for selecting the location of cargo placement. Lift operators are tasked with efficiently organizing cargo placement on the rail lines. The task requires knowing cargo sizes, compatibility of cargo sizes with rail, and what cargo is coming up from the barge. Some relevant examples of risks to sensemaking from Table 4 are attention and experience. For one thing, keeping apprised of the types of cargo coming from the barge and the available rail space requires consistent attention. For another, experience with different cargo types and matching sizes to chassis can help make the process more efficient with less likelihood of mistakes.

Decision-making is also relevant to cargo placement. While sensemaking focuses on understanding, decision-making focuses on the actual end choice someone makes. Some relevant examples of risks to decision-making from Table 5 are experience and stress. Experience can help lift operators place cargo in the best location, given how far the barge unload has progressed. Early in the barge unloading, loading containers in the front of the train will save travel distance at later points in the barge unloading. Extra stress caused by time pressure can reduce this efficiency and lead to less beneficial decisions.

Action, like detection, is a constantly applied aspect of the macrocognitive approach. Actions are being taken for all subtasks identified in Figure 20. Some relevant examples of risks to action execution from Table 6 include road conditions and experience. Similar to other instances of lift operation, operators need to be cognizant of the road conditions and how angles can impact their lift’s center of gravity. Actions that would be fine in typical conditions can lead to accidents due to potholes and hills. More experienced operators are more likely to adjust their actions to fit the environment than less experienced operators and with more accuracy.

Coordination for the loading of the train is more direct than the initial train unloading. All subtasks identified for train loading include verbal and non-verbal communication between the lift operator and truck drivers. Some relevant examples of risks to coordination from Table 7 include training and visibility. Training can help truck drivers and lift operators understand how to perform their tasks to stay safe and efficient. For example, training truck drivers on where and when to stop for lift operators to unload their cargo could improve safety and efficiency. The same is true for training lift operators to use the best practices for communicating with truck drivers about where they need them to be. However, like other communication-oriented tasks, visibility can impact the effectiveness of nonverbal communication and cues workers use to stay safe.

Post-Barge, Backload Empty Containers: Backloading the empty and outgoing shipments is the final process lift operators perform in the yard related to a specific barge. The goal is to place all the empty containers and outgoing shipments on the barge in a way that would be beneficial for the unload team in Seattle. The research team did not stay to observe this process, but a high-level flow can be found in Figure 21.

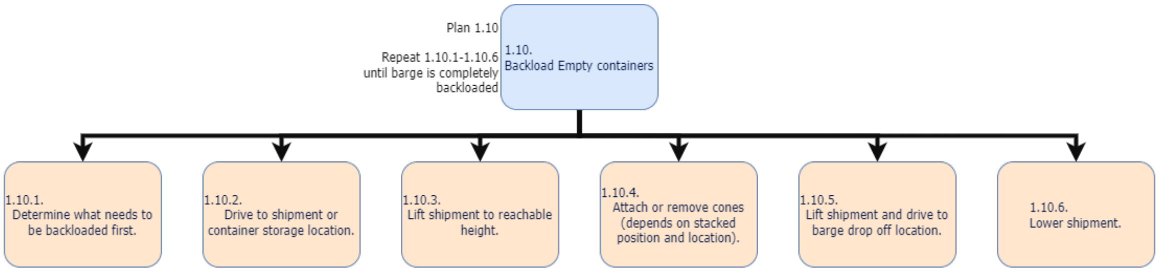

Figure 12. Diagram. A high-level hierarchical task analysis of backloading the barge. This task is primarily completed by lift operators.

3.3.2 ADS Trucking Operations

3.3.2.1 Methods

The research team employed various tools to examine the impact of ADS-equipped trucks on port operations. Some of the tools the team implemented are similar to those implemented in their initial analysis of port operations when there were only manual trucks in the yard. For example, interview and observation techniques were used to collect data, and the methods were modified to fit the available employees, equipment, weather, and timing. The following subsections outline the interviewing and observation techniques the researchers used for this portion of the demonstration.

Interviews: The research team conducted a mixture of group and individual interviews with nine participants during the data collection period in Whittier. The interviews were semi-structured and conducted during active work in the yard and office outside of active work. Participants included one safety driver/trainer from the ADS company, an engineer from the ADS company, a project manager from the ADS company, four forklift operators, a field manager, and one executive. The interview structure varied due to the dynamic nature of the port work and the availability of the subjects.

Walk-through: The research team was given equipment, functionality, and procedural walk-throughs of the ADS by the ADS company safety driver. First, the safety driver described the equipment and functionality of each device installed on the truck. Second, the safety driver walked the researchers through the process they take to inspect, start, and verify ADS truck operations as they currently work. Both walk-throughs were done in the garage with both automated trucks, three researchers, and the safety driver present.

Observations: The FO’s eventual goal is to use the ADS-equipped trucks during barge unloads. However, the research team could not observe a barge unload with the trucks running in automated mode. Instead, the research team worked with the FO and ADS company to set up two demonstrations. The first demonstration focused on the functionality of the ADS-equipped truck. The second demonstration involved a pilot test with one automated truck interacting with a lift in the upper yard.

The first demonstration focused on how the automation was designed to work, the procedures to operate the automation, and how the automation would interact with the environment. Researchers parked in the yard while the safety driver laid a trail, drove in automation mode, and demonstrated different maneuvers. The researchers were in contact with the safety driver for the entire demo using walkie-talkies.

The second demonstration, or pilot test, focused on the interactions between the ADS truck and lift operators. First, the safety driver laid down a trail from the lower to the upper yard. Next, one lift driver positioned themselves in the upper yard where they might wait for trucks to arrive during a barge, and the other waited in the lower yard by the stern ramp. The ADS truck was loaded and unloaded multiple times with various dynamic stop points in the upper yard. The truck would start and be loaded in the lower yard, drive into the upper yard on the set path, stop in the upper yard to be unloaded, and be sent back to the lower yard. The controls and communication strategies of the lift operators were observed. The pilot test included a researcher riding along in the upper yard lift and researchers observing from the lower yard.

3.3.2.2 Sociotechnical System

ADS: ADS implementation complexity increases as the control over operational or environmental elements decreases. Public road deployment, in which the least control is present, requires the most advanced perception and decision-making systems. Factors that influence control within a private yard can include characteristics such as repetitiveness of routes, degree of mixed traffic, presence of vulnerable road users, and public access to the site, among others.

Fundamentally, ADS technologies consist of a perception system that allows for referential placement of other vehicles and objects, localization of the ADS-equipped vehicle based on a mapping of the environment, a control system to execute the driving actions, and algorithms responsible for the planning and decision-making of those driving actions. Secondary elements of the ADS are expected to include redundancy systems, cybersecurity measures, effective power supply and energy management, and built-in validation checks.

The circuitous port activities in Whittier makes a GPS trail-based automation system the best fit. The work at the Whittier port is highly dynamic, and no lane-lines are available for the vehicle to use for navigation. Furthermore, the weather could cause an issue for visual navigation methods. Instead, a safety driver is required to record the path the vehicle will travel along that day. Once the path is set and the automation is engaged, the truck will follow the path, stopping at preset points decided by the driver, who records the path for loading and unloading.

The stop points along the path are static or dynamic. Static stop points are those created by the safety driver when recording the path the ADS will follow. The static stop point will always be in the lower yard, where lifts can load the truck from the stern and the side ramp. Lift drivers can change the dynamic stop point and will be located in the upper yard. Unloading the trucks in the upper yard requires more flexibility than loading in the lower yard because as the train is filled, the truck needs to adjust to accommodate the lift operator. Instead of a manual driver deciding where to line the truck up for the lift operator, the lift operator will indicate where they need the ADS truck to stop. Stop points are essential to the ADS implementation in Whittier.

The sensory system implemented by the ADS at the Whittier port is also essential for understanding the overall system. The ADS trucks will have cameras, but the primary method the ADS will use to detect and avoid collisions in the yard is rovers. Non-ADS vehicles in the yard will have a rover that provides the ADS trucks with high-resolution location data for all recovered vehicles. The ADS truck can then use the rover location data to alter the truck's behavior. ADS trucks will slow down when too close to a recovered vehicle, but the rovers allow that buffer to be significantly smaller than using another technology.

ADS Equipment: One significant change to the sociotechnical system in Whittier comes from the new equipment required for ADS operations. The ADS in Whittier can be broken into three major components: (1) the "brain," (2) the ADS truck, and (3) the external equipment. The brain, sometimes called the central server, is the central location where all of the ADS's individual parts connect and communicate through. See Table 8 for a general overview of equipment. The ADS truck and auxiliary equipment (see Figure 22) will be discussed in the following sections.

Figure 13. Photo. The primary ADS equipment. See Table 8 for equipment descriptions.

ADS Truck-based Equipment: The ADS trucks in Whittier are new, automatic transmission tractors with ADS components integrated into the original hardware. For simplicity, the ADS hardware comprises three distinct yet interdependent systems: sensory, control, and communication. Though each system is tightly interwoven, categorizing the equipment in this manner allows for a more organized and efficient discussion of the ADS technology. For example, some devices, such as a camera, may fit in sensory and control systems. However, the discussion about equipment is organized based on their primary functions.

The sensory system is dedicated to perceiving the vehicle's location in space and the vehicle's relation to other objects. The onboard sensory system for the Whittier ADS trucks includes differential GPS (DGPS) and front- and rear-facing cameras. The DGPS is a GPS sensor capable of tracking the location of an object with a higher degree of accuracy than traditional GPS.(xxix) The ADS truck has a DGPS on the front of the tractor cab, which is the primary method of determining the truck's location in the yard. The front- and rear-facing cameras are in the center of the front and rear windows of the tractor cab, respectively. The front- and rear-facing camera use computer vision algorithms to detect objects in, or around, the ADS's projected path of travel. According to the ADS developer, the cameras can trigger the ADS to stop the truck's motion and have the capability to detect people, vehicles, and traffic cones. Rovers are the primary method of object detection for ADS trucks, but as they are installed on other vehicles they will be discussed with the external equipment.

The control system is dedicated to issuing commands and programming new behaviors into the vehicle. The control system includes the automation control unit (ACU), the automated brake control, and the Service Vehicle Disconnect (SVD). The SVD knob is one of the two main controls used to engage the automated driving mode on the ADS trucks. Two SVD knobs need to be set to activate for the automation mode to be engaged, one on the outside rear of the tractor cab and one on the inside control panel. The automated brake control is another control needed to engage the automated driving mode. The automated brake control lever must be set to automation mode before the automation can control the parking and trailer brakes.

The ACU is the primary control method for ADS functionality for safety drivers. The ACU is in the center of the truck dashboard above the vehicle's radio and can control all the automation functions. The ACU has 15 mappable buttons with the secondary SVD knob for automated functioning. The ACU controls allow safety drivers to set a path, start automation mode, pause automation mode, stop all automated vehicles, change the exterior driving mode indicator lights' (hereto referred to as Andon lights) brightness, and ignore the AV's stop rule for external vehicle proximity using an override button. Currently, some buttons are labeled with a symbol representing their function, while other buttons lack a label representing their function. For example, the "drop points" button, located directly to the right of the play button is unlabeled but is required for creating a new trail. The button labels will not be finalized until the automated system is officially deployed. See G in Figure 22 for an image of the ACU in the ADS truck and I in Figure 22 for an image of the ACU in a lift.

The communication system transfers information to the central for processing and communicating with people around the vehicle. Communication with the central server is achieved using cell connectivity and does not have a user-facing indicator of status when devices are working correctly. The Andon lights indicate the vehicle's status to people in the yard. There are two automation status lights, each located by the side mirror of the tractor cab, and each contains three separate color lights: blue, green, and amber. The amber light represents the status of the parking brake and blinks when the parking brake is engaged. The blue light indicates automation mode, and the green light indicates manual driving mode. The amber light is always accompanied by a green or blue light, depending on whether the vehicle is in automated or manual driving mode while parked. See E in Figure 22 for an image of the Andon lights.

Table 8. Overview of equipment descriptions corresponding to Figure 22.

Letter	Equipment	Description
A	DGPS	A high-accuracy GPS device that determines the truck's location in the yard.
B	Front-facing Camera	A camera mounted at the top of the windshield facing forward that serves as the primary source of visual information for the automation system. Through computer vision and the front-facing camera, the automated system can detect vehicles, people, and cones.
C	SVD	The switch needs to be set to "On" for the automation system to be functional. Another switch inside the vehicle must also be set to "On" for the automated system to operate.
D	Rear-facing Camera	A camera mounted in the back window of the tractor cab. This camera can also detect objects like the front-facing camera but is mostly there to read the numbers on the containers.
E	Andon Lights	Three indicator lights are mounted on both sides of the tractor cab, right below the side mirrors. Blue indicates the automated system is active, green indicates manual driving, and amber indicates the parking brake is active. The lights flash continuously to indicate the mode the vehicle is in, and amber (parked) is always paired with the control mode.
F	Automated Brake Control	A lever used to switch between automated and manual braking. This lever needs to be set to automated mode before the automated system can drive. This lever allows the ADS computer to control the parking and trailer brake.
G	ACU	A customizable keypad for controlling the automated system.
H	Internal SVD	The internal SVD switch. Both the internal and exterior SVD switch need to be set to "On" before the vehicle can be put in automated mode.
I	Lift/ Remote ACU	Similar functionality and control capabilities as the ACU installed in the ADS truck. Every lift will be able to control the ADS trucks through the use of the keypad.

ADS Equipment on Other Vehicles: The ADS equipment includes the additional devices outside the ADS truck and central server that allow for remote control of the ADS truck and perception of mobile objects. Rovers and external/lift ACUs are the primary ADS equipment not installed on the ADS trucks. Rovers are an offboard sensory system installed on other vehicles, and the lift ACUs allow lift operators to control ADS trucks.

Rovers are the primary method the ADS uses to detect vehicles. Rovers are radio beacon devices placed on vehicles, such as lifts, driving around the yard during automated operations. The DGPS on the tractor and the rovers on other vehicles repeatedly send a heartbeat signal to the central server with their location. The location data is then used to prevent collisions in the yard using known vehicle geometry and movement information.

A buffer zone is an essential concept regarding rovers and ADS truck interactions. A buffer zone is the "safety bubble" around each ADS truck, where the truck will stop if something enters the bubble. There are two buffer zones: a slowdown (blue in Figure 23) and a stop zone (pink in Figure 23). The slowdown buffer zone is furthest from the ADS truck, while the stop buffer zone has a smaller tolerance. For example, if a vehicle with a rover passes into the slowdown buffer, the ADS truck will decelerate to a preset speed. If a vehicle with a rover enters the stop buffer zone, the ADS truck will stop. Buffer zones need to be tuned based on the context and operations.

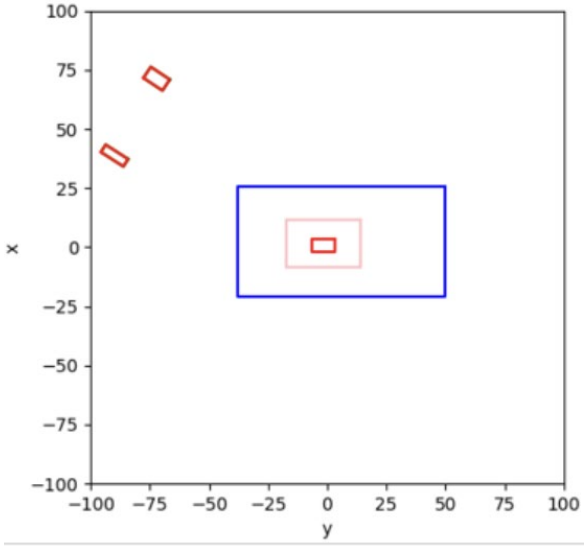

Figure 14. Illustration. Buffer zones surrounding a truck. The truck is the center red box, the blue box is a slowdown buffer, and the pink is a stop buffer. Note: The buffers are not to scale.

The main control component external to the ADS truck is the ACU installed in each lift. During barge off-loading, lift operators must be able to send commands to the ADS trucks. In some cases, the lift operators may need to create a new stop point, stop the ADS operations, or override the established buffer zone during conflicts. For example, suppose an ADS truck blocks a lift operator's destination because of a lift-ADS truck buffer conflict. In that case, the lift operator may press an override button to allow the truck to continue moving. See letter I in Figure 22 for an image of an ACU installed in a lift.

ADS Site Requirements: Several considerations for establishing or altering logistical or operational site components exist for the implementation of ADS technologies. These considerations are required both to establish the operational functionality of the ADS within its operational constraints while also ensuring the safety of all users during deployment.

> Operational Zones – The ADS technology functions by establishing several operational zones, manually determined during development of the system and defined using GPS-coordinate boundaries. These zones define the boundaries of the ADS during several automation modes and are required for functional operation. The zones are carefully defined within the ADS software and are based on rigorous testing and evaluation of potential paths of the ADS trucks. Zones may be further tweaked over time but should be relatively consistent and not dependent on temporary yard features such cargo storage or snowbank locations.
>
> First, the Autonomous Operating Zone (AOZ) determines the boundaries for where automation may be active and where a trail may be established (see Figure 24 for estimated zone locations; AOZ in green). The trail, or path of the ADS during barge unloading operations, is explicitly established within the AOZ and any points set outside the AOZ will prevent the trail from being confirmed within the management system app. Upon any deviation of the ADS outside the AOZ, a redirection into the AOZ will be attempted. If the deviation is not corrected, vehicle automation will be disabled until the truck is manually rerouted back into the AOZ.
>
> Second, the parking zone is established to stage vehicle automation during pre-trip inspections, as well as track where vehicles are when temporarily parked or kept during non-active barge time. The parking zone is separated from the AOZ as its use is primarily to hold or stage vehicles, and vehicles would not operate autonomously; however, automation modes can be tested for functionality and connectivity.
>
> Last, the dynamic zone represents the area in which the upper yard lift operator will have authority to establish a dynamic, temporary stopping point for the ADS truck. A dynamic stopping point is set by the operator based on where the operator would like to unload cargo from truck to railcar.

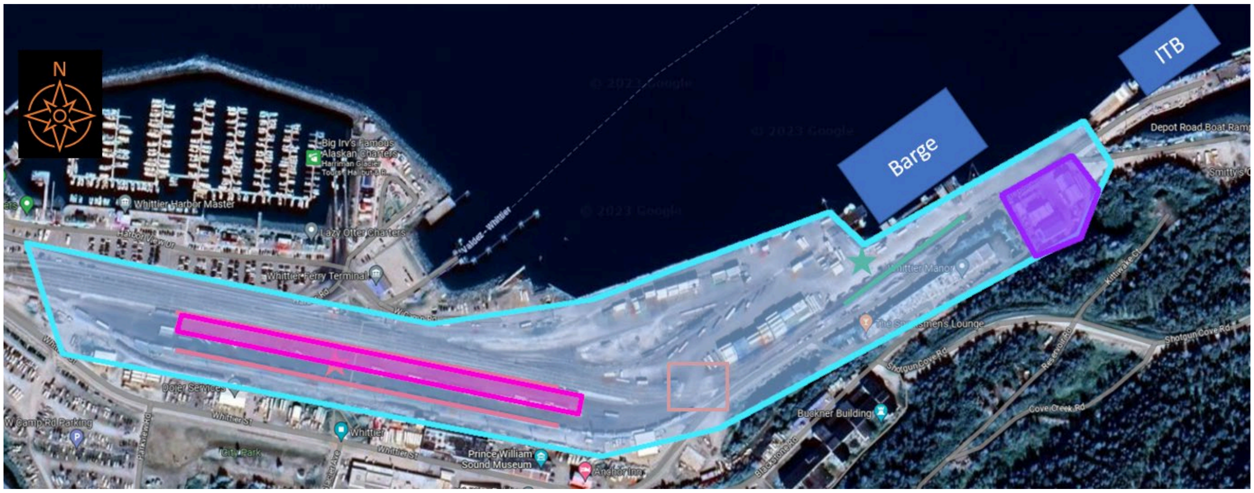

Figure 15. Illustration. Operational zones overlaid on the port. The blue area represents the AOZ, the purple area represents the parking zone, and the pink represents the dynamic zone.

Yard Requirements – Although the operability of the ADS is built based on the operations at the port, there are still several additional considerations throughout the introduction of automated systems. These limitations, or restrictions, placed on the private port/yard are required for minimal operation of ADS technologies, with the intention to optimize cargo haulage around the port. Given the ADS functions using GPS-tracing and tracking, robust and reliable connectivity is mandatory for operation of both the autonomous mode of the ADS-equipped vehicle as well as the proximity sensors attached to the rovers throughout the yard. Reliability in connectivity is threatened during certain severe weather or strong electromagnetic interference events. Other unrelated events, such as a large pull on the network from passing cruise ships, have led the ADS developer to install an LTE tower specifically for use by the ADS technology. This personalized tower ensures maximum connectivity upkeep and minimal interference across any GPS corrections applied. Further challenges to connectivity may result from the Alaskan yard, as GPS is reliant on satellite geometry, and if the arrangements of satellites over Alaska are insufficient, it may reduce GPS accuracy or signal.

An additional consideration is to ensure the layout of containers, cargo, equipment, and other large items or objects is functional for the purposes of operating within the AOZ. This may require establishing boundaries for where items may or may not be placed, including establishing the locations of high automation activity or AOZ trail width to ensure the capabilities of the ADS trucks are unhindered during operation and for ensuring proper sightlines for lift operators to identify locations of the ADS trucks.

Weather Considerations – During snowfall and severe weather, ensuring the routine plowing and clearing of the operating zone of the port is essential for the efficient operation of automated vehicles within its premises. While these vehicles may be capable of operating during severe weather (barring poor GPS signal), the physical movements of the heavy truck during severe weather conditions are not built into the automation algorithm. That is, if large amounts of snow or ice are present on the pathways of the ADS-equipped truck, the enacted behavior of the automation may be inappropriate. As such, regular plowing is crucial to prevent the accumulation of snow and ice that can hinder the mobility of AVs. Failure to maintain the infrastructure could lead to disruptions, delays, and potential damage to both the AVs and the cargo they transport.

However, the issue arises when the responsibility for the port's maintenance falls on the railroad corporation, the owner of the port. The railroad corporation may primarily focus on rail operations and may not have the immediate priority for routine port maintenance sufficient for ADS operation. This misalignment of responsibilities can result in challenges, as the port requires consistent attention to meet the needs of AV operations. The lack of timely plowing and cleaning could lead to operational inefficiencies, increased risk of incidents, and potential financial losses for businesses relying on the smooth functioning of the port. Collaborative efforts between the railroad corporation and marine transportation port operations are crucial to finding effective solutions that prioritize routine maintenance for the successful integration of automated vehicles within the port environment. One such effort may be to clearly set boundaries for defined operational zone maintenance and cleaning between the longshoremen and railroad engineers.

Pedestrian Restrictions – Other requirements based on specific ADS features rely on the absence of pedestrians for unfettered automated operations. The forward-facing camera within the ADS technology is continuously running a pedestrian-trained detector algorithm to determine the presence and location of pedestrians in view. The current application of the ADS requires no pedestrians visible during transit, such that any continual detection will immediately disengage the automation. This effort is planned to be extended only to the system AOZ; however, more research is required on effectively validating the distance measurements of the pedestrian detecting algorithms. This system functionality requires the addition of appropriate signage to indicate to the working longshoremen and to the public (of which none are authorized to be on site) that driverless systems are in operation. Although the detection of a pedestrian does disable automated features, any cycles involving the forced stop and subsequent restart of the automated system provides some level of risk as the cycling introduces an additional touchpoint between human and machine.

Training Requirements – Adding ADS to the port activities in Whittier will require workers present during ADS operations to receive additional training. In general, anyone who may encounter ADS vehicles needs a basic understanding of best safety practices for interacting with ADS trucks. For example, railroad workers must understand how the ADS trucks are expected to behave to avoid unexpected conflicts. For example, a rail worker could walk in the path of an ADS truck and cause an unexpected stop that may cause undesirable interactions with lift drivers.

More specific training will be required for the lift operators and other workers directly controlling the ADS trucks. Training for operators will need to capture laying a new trail, expected ADS truck behaviors, best practices for interacting with ADS trucks, and best practices for controlling ADS trucks all need to be trained. A mismatch between system capability and users' mental models can spell disaster in the right circumstances. Danger from misunderstandings is particularly risky if the integration of ADS changes the overall focus of the system. For example, if the system was lift-centric and lifts always had the right-of-way, but the integration of ADS trucks makes the system truck-centric, training needs to capture and transition that change. Training programs must be developed to capture the changes in the sociotechnical system ADS introduces.

Equally important to general-use training, site work crews should also be trained to recognize signs when equipment is not behaving as intended. ADS-equipped vehicles are not immune from failure or improper decision-making, and complacency could lead to problems for the FO. A partially occluded sensor, improper camera alignment, or reflective surfaces could lead to unexpected behavior. For example, improper distance location in the ADS could lead to an unexpected stop or collision. Workers should be equally prepared for and anticipate an ADS vehicle failing to stop for them, whether on foot or in a vehicle. By delivering training from both approaches, workers will likely interact more safely with the ADS-equipped trucks operating inside the port.

3.3.2.3 Base System Interactions

Pre-ADS port operations in Whittier are, or were, primarily lift-centric. Lifts enter the barge as soon as possible during a barge unload and begin transporting containers to their respective destinations in the yard. Truck drivers would adapt and adjust to lift operations with the prescript that lifts always have the right-of-way. The main goal of the trucks is to shorten the distance lift operators need to travel by providing a closer drop-off point for containers being transferred to the upper yard. Trucks are an important component to the off-loading of barges, but they are not the primary actor in the pre-ADS sociotechnical system.

Post-ADS implementation, lifts are still central to the operation, but trucks are elevated in the system hierarchy. While the general workflow in the yard stays close to the pre-ADS workflow, the trucks become an extension of lift operators. ADS trucks will follow their base path and be set to react to a limited number of contextual features. For example, ADS trucks will slow down or stop for detected pedestrians and vehicles, both those with and without rovers. Other behaviors, such as continuing to drive after the ADS detects a vehicle with a rover in the vicinity, creating a new stop point, or fully stopping the automation will be controlled by lift operators. The set behaviors of the ADS trucks require lift operators to understand ADS base behaviors, predict ADS behaviors, and adapt their own behaviors around the ADS.

The rest of this section will identify the base operations of lifts from the perspective of operators and ADS trucks from a behavioral perspective. First, we briefly outline the controls and displays from a lift operator's perspective. Second, we discuss how ADS trucks will operate, including the new responsibilities of lift operators.

Lift Operations: Lifts will have an additional control panel, the ACU, installed in their cabs. The ACU will contain all the controls needed for the lift operator to control the ADS trucks and needs to be integrated into the tasks operators already complete. In other words, while lift operators drive the lift, lift containers, make decisions regarding containers, and navigate the yard, they may also need to control the trucks. The high-skill bar required for successful lift operations makes working with operators to determine the location and timing of use for an automation control panel imperative. The placement and integration of new technology must take the current lift cab (see Figure 25) and operator's workflow into account.

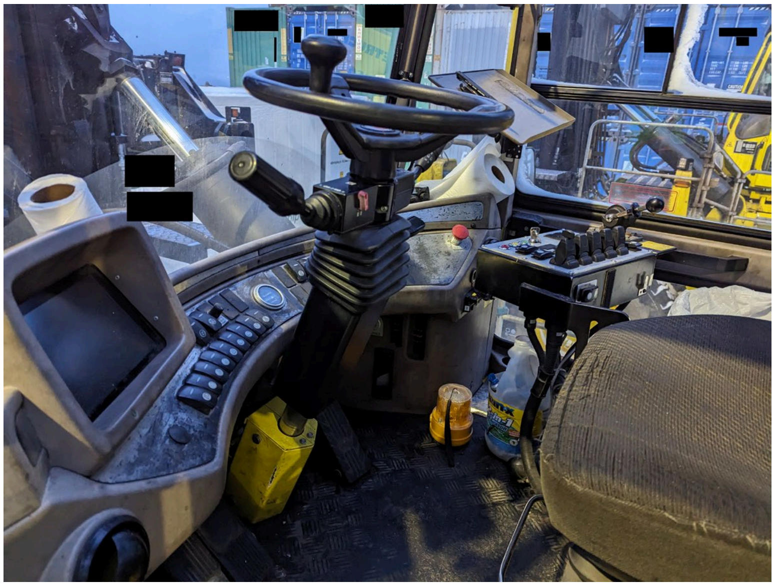

Figure 16. Photo. Cab of a lift used in the port of Whittier. Logos are redacted.

Currently, lift operators control various aspects of their lifts. First, lift operators must drive the lift. Driving the lift can be performed using the steering wheel or the mini-wheel. See Figure 25 for an image of a lift cab and Figure 26 for an image of the mini-wheel. Second, lift operators must control their mast and pick, paying attention to the angles and positions of each component. See Figure 27 for a mast and pick control panel. Finally, lift operators must also control the auxiliary equipment on lifts, including lights and wipers. In tandem with control, other cognitive processes, such as staying situationally aware and judging how weather impacts operations, are also occurring.

Figure 17. Photo. Mini wheel can be used to control the lift in lieu of the steering wheel. The mini-wheel folds down and takes the place of the left armrest. The brand name has been redacted.

Figure 18. Photo. Mast and pick control panel.

Truck Operations: Pre-ADS and post-ADS truck operations are similar but with slight differences. Pre-ADS trucks were manually driven and, as such, relied on the expertise of drivers for their efficiency and efficacy. Manually driven trucks with an experienced driver could increase the efficiency of a barge unload, but a novice driver might reduce efficiency. Experienced drivers in manual trucks benefit from the following:

1. Situational awareness: Maintaining awareness of their surroundings in a way that allows them to anticipate bottlenecks, navigate tight spaces, and adjust their routes based on real-time conditions.
2. Adaptability: The ability to adapt swiftly. A human driver can rapidly reroute, switch tasks, and respond to emergencies in a dynamic environment.
3. Predictive skill: The ability to predict where they are needed next. Based on lift behaviors and locations, an experienced driver could change their loading point and meet lifts in a location that reduces the lift's distance traveled.

ADS trucks, on the other hand, follow a strict set of behavioral guidelines. ADS trucks in the context of the port benefit from:

1. Consistent behavior: ADS trucks always behave the same way, with no deviations or improvisations. When this consistency of behavior is known to others in the sociotechnical system, it can ensure safety and efficiency.
2. Predictability: ADS trucks have set routes and loading points. Set loading points to ensure predictable locations for lift operators to find the trucks. Set routes ensure other workers in the sociotechnical system know the path ADS trucks will take and can work around them.
3. Growth: Based on system feedback, ADS can be improved over time. As the ADS trucks are used in context, the systems can be tailored to increase efficiency reliably and consistently. Loading locations can be identified, safety buffers improved, and new trucks added.

Truck operations will continue to achieve the same goals, but the rules and procedures through which these goals are achieved are less mutable with ADS. The experience and staffing of drivers cease to be a concern with the implementation of ADS. ADS trucks will always behave the same way by following the same routes, stopping in predetermined locations, and reacting to others in predictable ways. Where flexibility and adaptability are lost, consistency and predictability are gained.

3.3.2.4 Detailed Activities

The Whittier port is highly dynamic, and various activities are performed there. However, exploring the detailed activities we will discuss below will only apply to unloading barges. Furthermore, our exploration will highlight aspects of the system that will change with the implementation of ADS but will likely capture only some of the impact ADS implementation will have. The general workflows will follow the detailed activities outlined in section 3.3.1.4 and the analysis approach from the same section. The activities flow will be captured using hierarchical task analyses mixed with HRA techniques outlined in the same section. As the ADS implementation at Whittier has not been finalized, processes may change.

The task analyses will be broken down into pre-barge with ADS truck, barge with ADS truck, and post-barge with ADS truck activities. Pre-barge includes the ADS truck inspection and dropping of a new trail for automated operations. Barge with ADS truck includes removing cargo from the barge, transporting cargo via truck, and loading the train. Finally, post-barge with the ADS truck includes disengaging the automation. Safety drivers will likely be present in the initial stages, but the end goal of ADS implementation is to have lift operators control the ADS trucks as needed. Therefore, each task will be from the perspective of lift operators and assume no safety operator is present in the AVs. Our analysis also assumes that the automated system works as intended.

Pre-Barge with ADS truck: In the context of pre-barge activities, the goals remain fundamentally the same. Before the barge unloading, the FO and the SORC must complete a series of tasks. These tasks include extracting the inbound rail from the barge by the SORC, the pre-barge operations safety briefing, and the setting of the side ramp. For more information on pre-ADS implementation pre-barge activities, see section 3.3.1.4 (Pre-barge). However, despite the same primary activities, several new activities are introduced with the implementation of ADS. Two primary additions to the pre-barge activities are the ADS truck inspection and dropping a new trail for automated operations. As with the rest of this section, these activities are subject to change as the ADS is further developed.

ADS truck inspections are a new task the FO will need to perform before using the ADS trucks for barge operations. While pre-trip inspections are typical for tractor-trailers, adding the ADS and the equipment required to make ADS work requires additional inspection procedures. Operators must examine all the exterior and interior ADS equipment for damage, loose wires, or sensor occlusions to ensure the vehicle is fit for automated operations. Once the operator ensures the hardware is free from damage, the functionality of the automation system needs to be tested. During the inspection process, the functionality test finishes with evidence that the system can enter an ADS-ready state, not a demonstration that the ADS can successfully drive a previously dropped trail. Some of the hardware inspection can occur in tandem with the base pre-trip truck inspection, but the functionality inspection, where the ADS functionality is turned on, requires additional time. A high-level representation of the ADS inspection process can be found in Figure 28.

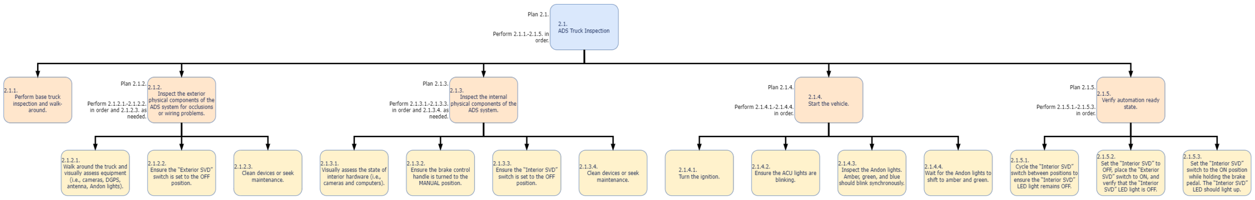

Figure 19. Diagram. A high-level hierarchical task analysis of ADS truck inspection. Note: tasks can be further broken down but were simplified for space. Lift operators or other FO employees will perform this task.

The ADS truck inspection is a crucial addition to pre-barge activities. Any issues with the ADS can result in a loss of efficiency or a potential disaster. In the case of a loss of efficiency, any time the ADS shuts down during operations, another worker will need to leave their post and restart the automation. In the worst-case scenario, a lift operator may need to drive the truck manually for the duration of the barge, or the truck might need to be decommissioned while repaired. In the case of a potential disaster, a dirty camera or issue with the DGPS could lead to a collision in the yard. A collision could cause damage to pedestrians and equipment.

The rest of this section focuses on a more detailed macrocognitive analysis of the “ADS Truck Inspection” task.

Macrocognition and ADS Truck Inspection. Detection is a critical and repetitive process for ADS truck inspection required for every subtask in the procedure (see Figure 28). The primary goal of the ADS truck inspection is to detect problems with the ADS equipment before attempting to use the technology in actual operations. Some relevant examples of risk to detection for the ADS inspection from Table 3 are object salience, stress, and fatigue. For example, detecting physical flaws with equipment will depend on how conspicuous the damage is. A frayed DGPS wire could be far less noticeable than the sensor puck being damaged, especially if the wire damage is at an entry point. Barges can also arrive at any time of day, causing fatigue and potentially stress that may interfere with taking the time or having the mental capacity for detecting problems.

Sensemaking is relevant anywhere detection is relevant during the ADS truck inspection. Sensemaking for the ADS inspection process culminates in the operator determining the system’s state based on their equipment observations. If damage is detected on a wire, the operator must use their experience to determine if the damage is cosmetic or functional. Some relevant risks to sensemaking for the ADS inspections from Table 4 are failed detections or poor training. For example, if an operator has not had sufficient training to understand the ADS equipment and how each part impacts the whole, they may not know if the system is or is not at risk based on the equipment’s state. Missed detections, resulting from a lack of experience or training, could also give an operator an incorrect mental model of how the system is functioning. The HMI design can also impact starting the vehicle and verifying the automation ready state in Figure 28. Clear and understandable signals are required to understand the system state.

Decision-making is essential for the ADS truck inspection after the operator recognizes a problem with the ADS equipment. Some relevant examples of risks to decision-making during the ADS inspection process, as shown in Table 5, include poor training and previous experience. For example, if the inspection operator had previously ignored damage or occlusions on devices and the ADS worked without incident. Experience can be compounded by poor training, and inspectors can choose to allow trucks to operate despite the potential dangers.

Action is crucial to any interaction, and the ADS inspection is no exception. Interacting with the truck’s ADS controls is pivotal to the inspection process, for example, in step 2.1.5. in Figure 28. Despite action being critical to the ADS inspection process, action errors are unlikely. Action errors are rare, to begin with, but in a situation where time pressure, lighting, and weather are not likely to be a problem, action errors become even less likely. Still, stress and the HMI could provide examples of risks, as shown in Table 6. The HMI design could provide a venue where a correct intention could lead to an improper action in the right conditions. A stressed or fatigued operator may press or turn incorrect inputs if the layout of inputs allows for mistouches.

Coordination is more critical for the overall process of ADS inspection than it is for any individual step. While one operator will likely complete all the inspection processes, the completion of the ADS inspection needs to be known to the supervisory and safety staff. Examples of risks to coordination for the ADS inspection are shown in Table 7, which includes safety culture and role awareness. Depending on the safety culture at the facility where the ADS inspection occurs, communication might not occur after a completed ADS inspection. In a highly dynamic setting, the lack of communication or the assumption of a successful inspection could lead to a situation where the vehicle is not inspected, or problems are never communicated to the appropriate individuals.

Trail Drop for Autonomous Operations. Creating a path for the ADS trucks to follow, called "dropping a trail," is another new task the FO must complete during the pre-barge preparations. The ADS in Whittier operates using a record-play model where a manual drive is recorded by a driver and then repeatedly replayed by the ADS. Dropping a new trail is the process of recording the initial drive that the ADS trucks will continue to drive during operations. During the initial drive recording, the manual driver can also create locations where the ADS trucks will stop, called stop points. After the manual drive is completely recorded, the driver would contact a supervisor, who has access to the ADS web app (see section 3.3.2.2), to ensure the trail was properly recorded. Once a trail is properly recorded, the driver can prepare the truck for automated operations and proceed to their typical shift location. See Figure 29 for a more detailed workflow for dropping a new trail.

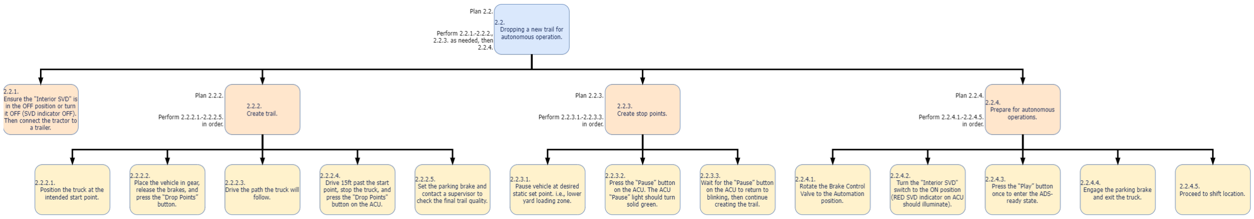

Figure 20. Diagram. High-level hierarchical task analysis of dropping a new trail for autonomous operations. Note: tasks can be further broken down but were simplified for space. Lift operators or other FO employees will perform this task.

The ability to create new trails is an important feature of the ADS trucks at the Whittier port. For one thing, the Whittier port is a highly dynamic space that is always changing. The yard's overall layout and the operators' needs are always shifting. The number of stored containers, the location of stored containers, the locations containers need to be transported, and even how crowded the port is during operations remain fluid. The weather also makes the ability to lay new trails important. Whittier weather can be unforgiving, with abundant rain, snow, wind, and ice throughout the year. As ice builds up in the yard, previously set trails may no longer be safe to continue using as the uneven ground and slick texture can lead to operation problems. The ability to set new trails with each barge fits the dynamic nature of the sociotechnical system and ensures the ADS can continue being useful throughout the year.

The rest of this section focuses on a more detailed macrocognitive analysis of the "Trail Drop for Autonomous Operations" task.

Macrocognition and Trail Drop for Autonomous Operations. Detection is critical for driving the vehicle and monitoring the state of the trail creation. Port operations are dynamic, and the continuous perception of hazards is crucial to the safety and efficiency of operations. Some relevant examples of risks to detection from Table 3 are attention and workload. For example, during a trail's creation (step 2.2.2. in Figure 29), detecting environmental hazards such as pedestrians is critical to continue safe operations. The increased workload of monitoring an automated system and paying attention to one's surroundings could lead to worse environmental hazard detection. Unexpected pedestrians or unseen potholes can lead to potential issues with a new trail or operations in general.

Sensemaking is relevant for creating new trails, creating stop points, and preparing for automated operations (see Figure 29). An accurate mental model of barge operations, the needed trail to fit operations, and the functionality of the ADS is required to set an effective new trail. Some relevant examples of risks to sensemaking from Table 4 are the HMI and training. For example, an inexperienced operator might be able to set a standard trail, but they would not be able to adapt to a new yard configuration as well as a veteran barge worker. Furthermore, depending on the quality of the feedback provided by the HMI, the operator may or may not be able to determine what, if any, data was recorded. Feedback is crucial for a good mental model of a system.

Decision-making is more critical for setting a new trail at the management level than at the operator level. By the time a new trail is set, the operator will likely be following predetermined routes and stop points that have been agreed upon by the entire operations team. The actual path and the location of stop points depend on the specific characteristics of the barge, yard layout, and weather conditions. Either way, the decisions will not likely be in the moment but rather premeditated. Some relevant examples of risks to decision-making from Table 5 are expectation and experience. The expectation of a particular barge's progress based on weather conditions, personnel, and yard layout might not align with reality. Inexperience or experiences that challenge previous experience may impact a trail planner's ability to foresee the impact of a particular trail or stop points.

Action is present in every subtask identified in Figure 29. Actions about driving, controlling ADS functions, and communicating with other operators can all be impacted by risk factors. Some relevant examples of risks to action from Table 6 are the weather, road conditions, and fatigue. While laying a new trail takes place before a barge, a barge can arrive any time of the day, making irregularity in sleep potentially impact fatigue. Besides the impact of fatigue on one's actions, making them less smooth, weather and road conditions can also impact actions. Severe winter conditions frequently impact Whittier, and a cold, icy port could lead to inaccuracy of behavior. For example, one might slide when braking and place a stop point further along a trail than intended.

Coordination is important in both validating the capture of a trail, ensuring the safety of the operator enabling the ADS, and ensuring all personnel working around the ADS grasp the expected locations of the trucks (one of the goals of Figure 29). In a team environment where each operator has a control panel that can command the ADS trucks to move, communication is crucial when moving around the trucks on foot. Without clear communication, a lift operator can give the truck a "Play" command while another operator is leaving the truck. Additionally, a predictable path is important for lift operators to be able to work around the ADS trucks. Some relevant examples of risks to coordination from Table 7 are equipment failures and safety culture. For example, set safety procedures and consistent communication can prevent a lift operator from pressing the "Play" button to start the ADS while an operator is still around the truck. Complacency and poor equipment maintenance could lead to risks for personnel.

Barge with ADS Truck: Post-ADS implementation barge activities have similar goals to the pre-ADS barge activities. However, unlike the pre-barge activities, the implementation of ADS impacts the tasks being performed rather than adding new ones. Similar to pre-ADS, barge activities begin once the lift operators can begin removing cargo from the barge and end after the last container is removed. The lift operators' goal is to unload the barge as quickly as possible by bringing the containers to their respective destination locations in the port. See section 3.3.1.4 (Barge) for more information regarding the pre-ADS barge activity task flows and goals. As with other parts of this section, these activities are subject to change as the ADS is further developed.

Remove Cargo from Barge after ADS Implementation. Removing cargo from the barge post-ADS implementation is similar to pre-ADS implementation. The primary difference between pre-and post-ADS operations is the added task lift operators have of controlling the ADS trucks. Choosing the cargo to remove from the barge and transporting it to its final destination is essentially the same. Even keeping track of where the trucks are located if an operator needs to get their cargo to the upper yard is similar to pre-ADS. However, keeping track of moving ADS trucks, loading them, and commanding them to continue their path are altered.

Keeping track of where the ADS vehicles are is important for all lift operators post-ADS implementation, not just the lift operators transporting goods to the upper yard. Given the strict capabilities of ADS trucks, the system is forced to shift from a lift-centric to a truck-centric model. Pre-ADS, lifts always had the right-of-way. Pre-ADS lift operators did not ignore other moving vehicles, but if a truck and a lift needed to cross paths, the lift was given precedence due to their limited field of view and the importance of unloading the barge. However, ADS trucks are limited in their ability to perceive and react to the world like a real driver, requiring lift drivers to be more flexible.

The loading and commanding of automated trucks have also changed in post-ADS port operations. In pre-ADS implementation, experienced truck drivers could predict and adapt to the needs of lift operators. For example, a lift exiting the barge from the stern ramp might be met by a truck as they clear the barge. Post-ADS, the trucks will always be in the same loading zone, have indicators communicating they are parked, and require the lift operator to press a button to have them continue on their way—efficiency in the form of standardization rather than expertise. See Figure 30 for a high-level task breakdown of removing the cargo from the barge after ADS implementation.

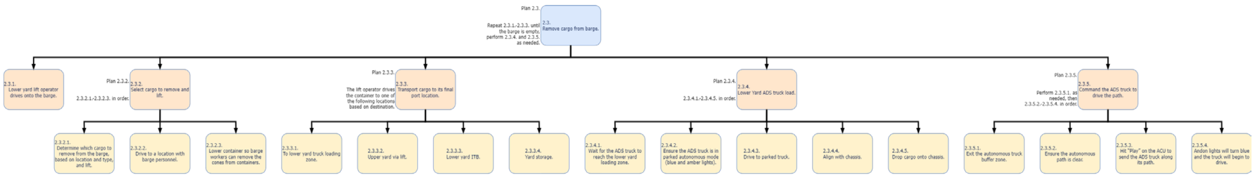

Figure 21. Diagram. High-level hierarchical task analysis of removing the cargo from the barge with ADS implemented. Note: tasks can be further broken down but were simplified for space. Lift operators will perform this task.

The rest of this section focuses on a more detailed macrocognitive analysis of the "Remove Cargo from Barge after ADS Implementation" task.

Macrocognition and Removing Cargo from Barge after ADS Implementation. As in most other processes, detection plays a critical role in removing cargo from the barge after ADS implementation. A lift operator must detect and attend to workers on foot, other vehicles, cargo identification numbers, and ADS trucks, to name a few. Detection is essential for every subtask of Figure 30, especially for steps 2.3.3–2.3.5. Some relevant examples of risks to detection from Table 3 are attention and workload. With the added workload of closely attending to the ADS vehicles and controlling them, detecting critical items in the environment could suffer. The increased workload, though minimal during some tasks, like selecting and removing cargo from the barge and having to attend to the ADS trucks while driving during other tasks could reduce performance.

Sensemaking, like detection, is vital for most subtasks. However, removing cargo from the barge post-ADS implementation, detection is most relevant for driving in the yard and controlling the ADS (steps 2.3.3–2.3.5. of Figure 30). Some relevant examples of risks to sensemaking from Table 4 are the HMI and training. The HMI of the ACU in the lift can serve as a direct view into the ADS truck's behaviors if designed well. Take the override for example. If an ADS truck stops near two lift operators, the HMI can provide feedback as to which entered the truck's buffer. If there is no visual feedback that an operator's lift stopped the truck, then both lift operators are blind to the cause of the lift's behavior. On the other hand, if an LED lights up above the override button to indicate the lift has entered a truck's buffer, then the lift operators know if they need to move or use the override button. Better training can also prepare lift operators to understand the behavior of ADS trucks.

The main decision-making points for removing cargo from the barge post-ADS implementation are determining which cargo to unload, the cargo's destination in the yard, and if waiting for an ADS truck is worthwhile (steps 2.3.2.1, 2.3.3.1, and 2.3.3.2 in Figure 30). Regarding automation, the primary decision point occurs when an ADS truck is not in the lower yard loading zone, and the cargo needs to be transferred to the upper yard. The lift operator can transfer the cargo without a truck or wait for a truck to enter the lower yard loading zone. Some relevant examples of risks to decision-making from Table 5 are experience and personality. Depending on the lift operator's impulsivity and experience, they may drive to the upper yard at inopportune moments. A more experienced or less impulsive lift operator might make a better decision regarding waiting for an ADS truck to reach the loading zone or driving to the upper yard themselves. Driving to the upper yard in a lift increases exposure to other vehicles and can lead to inefficient barge offloading.

Action is relevant for all unloading the barge post-ADS implementation subtasks. However, commanding the ADS truck to continue driving along its path (step 2.3.5 of Figure 30) is particularly interesting concerning post-ADS operations. New required tasks can add a new point of potential failure, and interacting with the ACU is new. Some relevant examples of risks to action from Table 6 are workload and fatigue. An unintentional slip of the hand or selecting the wrong button on the ACU is more likely as workload and fatigue increase. Unloading a barge could take a significant amount of time at irregular hours.

Coordination is paramount for removing cargo from the barge post-ADS implementation. Lift operators already coordinate through CB radio and body language regarding their intended behaviors and the cargo they remove. Post-ADS implementation will also require lift operators to communicate regarding the ADS trucks and their behaviors. For example, communication might be critical in a lift operator's decision to independently drive cargo to the upper yard (see Figure 30). Some relevant examples of risks to coordination from Table 7 are role awareness and visibility. Post-ADS implementation, all lift operators are expected to have control of ADS vehicles via the ACUs in the lifts. An ADS truck could stop because of lifts close to its buffer zone, but poor communication due to a lack of role awareness could lead to confusion and inefficiency. Lack of visibility due to fog or location could also impact the head lift operator from seeing an issue with an ADS truck, and each lift operator needs to know what their role is in controlling the trucks to react appropriately.

Transport Cargo via Truck after ADS Implementation. The transportation of containers via truck from the lower to the upper yard is completely handled by the truck's automation, with a few exceptions. First, the trucks can be paused, told to continue, or stopped by any lift operator at any time. Second, the upper yard lift operator can create dynamic set points. Dynamic set points are unique to the upper yard and allow a lift operator to move the stop location of the ADS trucks as the train is filled. Without input from lift operators, the ADS trucks will drive between the lower yard static set point and the upper yard dynamic set point along the prescribed route (See Figure 24). At each stop point, the vehicles will stop until a lift operator sends the continue command.

The ADS truck behavior, a secure AOZ, and the mental model of workers are particularly important regarding safe port operations. The ADS truck behaviors, including speed, buffer zone conflict reactions, conflict reactions with objects or pedestrians not tagged with a rover, to mention a few, impact safety. For example, how the ADS truck reacts to a pedestrian along the ADS trail can impact the safety of everyone around the truck. A secure AOZ mixed with accurate mental models should be a protective barrier for incidents. A secure AOZ ensures a clear space where the ADS vehicles can operate and ensures minimal unexpected conflicts; fewer unexpected pedestrians translate to fewer unexpected stops. Accurate operator mental models of ADS behaviors, ensure maximum situational awareness and better predictive operator behaviors; a better understanding of the ADS behavior should lead to a better understanding of how to navigate safely around them.

Load Train after ADS Implementation. Loading the train in the upper yard post-ADS implementation is significantly impacted by the presence of ADS. While the overall task mirrors the pre-ADS train loading task described in Figure 20, the upper yard lift operators are now responsible for navigating around and controlling the ADS trucks. The most efficient location for the trucks to stop in the upper yard to be unloaded hinges upon where empty train car spaces are. Depending on the rate of trucks coming into the upper yard, two ADS trucks are planned, the control of the dynamic unload point can take time to manage. The upper yard operator needs to set the stop point, wait for a truck to be in position for unloading, remove the container, send the truck along its way, and load the cargo on an appropriate empty train car while also planning for the next truck and the next stop location. If trucks follow one after another, the ability to set another dynamic set point may be hindered.

Additionally, the upper yard presents a unique challenge for lift operators due to the narrowness of the loop ADS trucks will drive along (see Figure 13). The narrowness of the upper yard vehicle loop means that the lift operator may need to operate up to two ADS vehicles at a time in close quarters, and that stop points could be placed in the wrong location. The close-quarters operations pose a challenge due to the limited field of view lift drivers have and the lift operator's responsibility to control the ADS trucks. The narrowness of the loop may cause issues for the dynamic stop point locations because the stop points will stick to the path nearest to the lift operator. A truck continuing along the automated path to stop on the mountainside of the upper yard could cause a severe slowdown, especially if the upper yard operator sets a new stop point on the bay side before the first vehicle stops. A truck that misses its stop point would continue to the lower yard loading zone with its original cargo until commanded to return to the upper yard. See Figure 31 for a high-level breakdown of the loading the train task after ADS implementation.

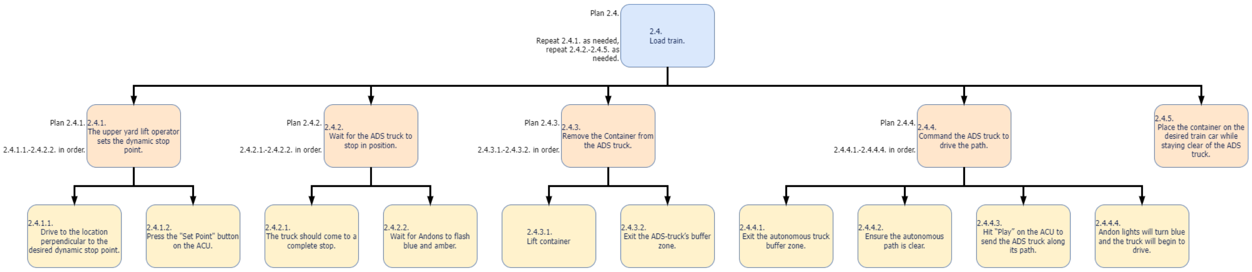

Figure 22. Diagram. High-level hierarchical task analysis of loading the train in the upper yard with ADS implemented. Note: tasks can be further broken down but were simplified for space. Lift operators will perform this task.

The rest of this section focuses on a more detailed macrocognitive analysis of the "Load Train after ADS Implementation" task.

Macrocognition and Loading Train after ADS Implementation. Detection is essential for every subtask of loading the train in the upper yard after the implementation of ADS. Waiting for the ADS truck to come to a complete stop (2.4.2 in Figure 31) and placing the container on the train while watching out for ADS trucks (2.4.5 in Figure 31) have safety implications for failed detections. For example, some relevant examples of risks to detection for those two tasks from Table 3 are visibility and workload. Lift operators in the upper yard will take on a more significant workload after ADS implementation than manual vehicles. Navigating around other vehicles, deciding where each type of cargo needs to go on the train, setting up stop points based on train car availability, and being aware of both truck states will be required for lift operators in the upper yard. For example, not detecting what state the automated trucks are in could lead to a collision or cargo being damaged. Not detecting an ADS truck could lead to a collision or inefficient operations.

Sensemaking is also essential for each loading the train subtask after ADS implementation. However, sensemaking is particularly interesting for choosing a dynamic stop point (see Figure 31) and loading the train while staying clear of the ADS trucks (see Figure 31). Some relevant examples of risks to sensemaking from Table 4 are attention and fatigue. Understanding where to place a dynamic stop point requires knowledge of the container size transported to the upper yard and where that container must be put on the train. If fatigue sets in or there is a lapse of attention, inefficient stop points might be set. Additionally, predicting when the two trucks will arrive and how to handle each stop point requires a complete understanding of how to best load the train.

Fatigue and lapses of attention can reduce the load operator's capability to gather the necessary information for efficient stop-point creation after a long shift.

Decision-making is most relevant for setting the dynamic stop point for ADS trucks (see Figure 31) while loading the train. Setting the stop point is essential for efficiency and safety in the upper yard, as poor stop point placement could lead to longer distances for lift operators to travel and trucks being parked in unexpected places. Some relevant examples of risks to decision-making from Table 5 are workload and experience. Decision-making regarding where stop points should be based on the train composition will benefit significantly from experience and vice versa. The time a barge takes, tied in with a high workload, could lead to more inefficient placement of stop points as the lift operator's mental bandwidth is reduced and becomes more strained.

Action is particularly relevant for removing the container from the ADS truck (see Figure 31) and commanding the ADS truck to return to the lower yard (see Figure 31). Some relevant examples of risks to action from Table 6 are road conditions and fatigue. The placement and removal of containers require precise placement of the top-pick cone locks. Fatigue may lead to more variability in the lift operator's movements and impact their precision as time passes. Furthermore, road conditions can lead to unexpected impacts on the placement of their lift. For example, a large divot in the road caused by ice could lead to an unexpected drop in tire elevation and change lift tilt, potentially reducing action accuracy.

Coordination is relevant for loading the train in that good coordination throughout the task can lead to a reduced workload for upper yard lift operators. Good coordination and communication can provide information about the types of loads transported to the upper yard and the locations of ADS trucks. Without communication, the upper yard lift operator needs to track each ADS vehicle, determine the type of cargo the trucks are carrying, and determine where the lift needs to be based on the gathered information. Some relevant examples of risks to coordination from Table 7 are equipment failures and ambient noise. For example, typical operating noises can make the radio challenging to hear but add wind noises and potential equipment failures, and all the workload falls on the upper yard lift operator. The expanded workload can lead to safety and efficiency problems.

Post-Barge with ADS Truck: The post-barge activities post-ADS implementation will have one additional task on top of the ones outlined in section 3.3.1.4 (Post-Barge). Pre-ADS implementation, backloading the empty and outgoing shipments is the final process lift operators perform in the yard related to a specific barge. Post-ADS implementation, lift operators will also need to disengage the automation. While manual trucks would be parked by their drivers after a barge, the ADS will need to be disengaged and then be parked.

Routine Shutdown. After a barge is completely unloaded, the ADS trucks will no longer be needed for port operations. The backloading process, described in Figure 21, is performed without the use of trucks. Therefore, before the backloading process begins, an FO employee will need to disengage the automation, disable remote control, and store the truck out of the way of operations. Disengaging the automation using the "All Stop" button ensures that the trucks exit automation mode and makes the trucks safe to approach on foot. Once the trucks have been approached, the "Exterior SVD" switch can be used to disable automation engagement and then the operator can store them out of the way. See Figure 32 for a high-level breakdown of a routine shutdown.

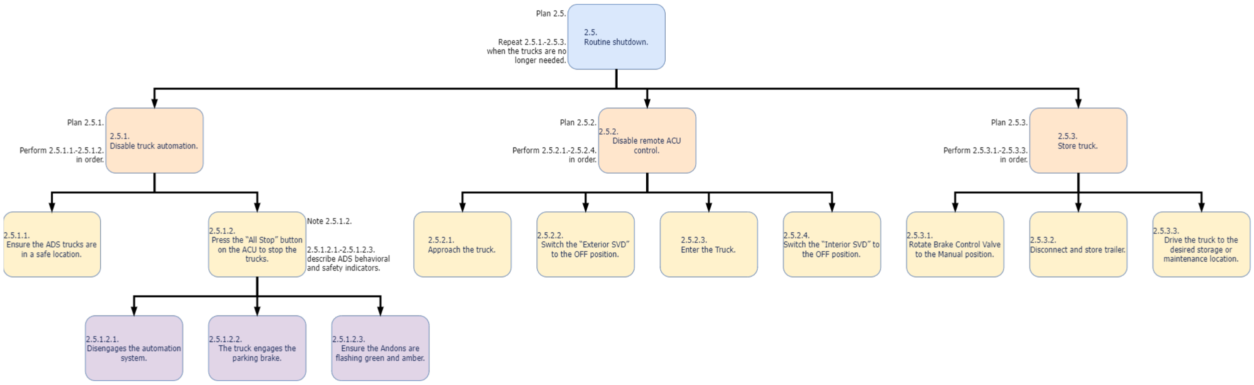

Figure 23. Diagram. High-level hierarchical task analysis of a routine shutdown of ADS vehicles. Note: tasks can be further broken down but were simplified for space. Lift operators or other FO employees will perform this task.

The rest of this section focuses on a more detailed macrocognitive analysis of the "Routine Shutdown" task.

Macrocognition and Routine Shutdown. Detection is essential for every subtask of routine shutdowns on the ADS trucks but is particularly important when disabling automated trucks (see Figure 32). Approaching the ADS truck (see Figure 32) involves risks if the truck is capable of moving independently. For example, some relevant examples of risks to detection for those two tasks from Table 3 are occlusions and fatigue. The routine shutdown will always occur at the end of a shift; therefore, fatigue can play a significant role in all forms of detection. For routine shutdowns, detecting the state of the Andon lights is crucial to the safety of operators. If the truck is still in automation mode (Andon lights are blue), the vehicle can begin moving while the operator approaches the truck. Occlusions, or fatigue, can lead to an operator missing the Andon indicators and finding themselves in a potentially dangerous situation.

Sensemaking is also essential for the routine shutdown of ADS trucks. While disabling the truck automation (see Figure 32) and disabling remote ACU control (see Figure 32), a correct understanding of the vehicle's abilities in each state is paramount. If an operator misunderstands the truck's functionality while it is in parked/automated mode (Andon blue and amber), they may approach the ADS when it can still operate. Some relevant examples of risks to sensemaking from Table 4 are training and motivation. For example, poor training of the ADS vehicle states can lead to a pedestrian-truck conflict that might easily be avoided. In addition to poor training, the motivation to end a shift might also create a situation where the operator is rushing and ignores potential hazards.

Decision-making is always relevant but does not particularly fit any one subtask for routine shutdowns of ADS trucks (Figure 32). However, the timing at which ADS trucks are taken out of the yard, and the routes taken by the driver are influenced by decision-making. Some relevant examples of risks to decision-making from Table 5 are workload and experience. Depending on the demands at the end of a shift, such as backloading the barge (Figure 21), operators may wait to shut down the vehicles, impacting the truck's fuel use. Additionally, inexperience with the

ADS and the end-of-shift activities may lead to poor route choices for operators driving the trucks to their storage locations, potentially leading to inefficiencies or safety-critical events.

Action is particularly relevant for disabling the ADS in the ADS trucks (see Figure 32). The "All Stop" button needs to be pressed for the safety of the operator approaching the vehicle. If the "All Stop" button is not pressed, the ADS truck can be commanded to move by lift operators, either by accident or purposefully. Some relevant examples of risks to action from Table 6 are fatigue and the HMI design. The HMI design needs to communicate the state of the vehicles and disable input at specific times. A fatigued lift operator may misunderstand a poorly designed HMI or even press the wrong button at the wrong time.

Coordination is relevant to all stages of the routine shutdown (Figure 32). Good coordination and communication ensure the ADS stays inactive during the approach and shutdown procedure. Additionally, good communication can ensure all other workers are aware that the trucks will be moving outside the prescribed route. Some relevant examples of risks to coordination from Table 7 are equipment failures, ambient noise, and role awareness. Like other coordination dangers discussed, typical operating noises can make the radio challenging to hear but can be worse when adding wind noises and potential equipment failures. An operator shutting down the system without an awareness of the dangers to other operators by violating ADS truck movement expectations could lead to further incidents.

3.3.2.5 Testable Metrics

The safe and efficient deployment of the ADS technologies warrants a comprehensive evaluation of the system during ADS-enabled barge operations. A sample of potential metrics are listed in Table 9 that capture various performative criteria by which the ADS deployment may be evaluated or tracked over time. Any comparisons of metrics across vehicle automation modality would need to be performed during both manual and automated modes. Comparisons of automation over time may highlight various elements of deployment (e.g., sensor degradation, weather or seasonal impacts, algorithmic improvements, training gaps, etc.) and systematic or unusual differences would need to be more carefully evaluated. A trip, for the purposes of the Port of Whittier, consists of one complete loop from the loading at the barge to the unloading onto the railcar, back to the barge awaiting another load.

Table 9. Potential metrics for ADS evaluation at the Port of Whittier.

Metric	**Value**	**Exposure**
Crash/Near-crash with another ADS-equipped vehicle	Safety	Per barge
Crash/Near-crash with Rover-equipped vehicle	Safety	Per barge
Crash/Near-crash with vehicle without Rover	Safety	Per barge
Crash/Near-crash with pedestrian	Safety	Per barge
Crash/Near-crash with object or animal	Safety	Per barge
GPS deviations from trail (count)	Safety	Per trip
GPS deviations from trail (maximum deviation)	Safety	Per trip
GPS deviations from trail (average deviation)	Safety	Per trip
Number of unique pedestrians detected (count)	Safety	Per trip
Distance to known objects (minimum distance per object)	Safety	Per trip
Vehicle speed (match to target speed)	Safety	Per trip

Metric	Value	Exposure
Vehicle acceleration (match to target acceleration parameters)	Safety	Per trip
Vehicle deceleration (match to target deceleration parameters)	Safety	Per trip
Accurate localization (matched to webapp)	Safety	Per second
Vehicle correct stops at locations within margin of error (percentage)	Safety	Per barge
Vehicle correctly responds to buffer override (percentage)	Safety	Per barge
Vehicle correctly responds to lift's automation engage command (percentage)	Safety	Per barge
Vehicle automation kickout due to pedestrian (count)	Safety Efficiency	Per barge
Vehicle automation kickout due to other error (count)	Safety Efficiency	Per barge
Emergency “All Stop” enacted (count)	Safety Efficiency	Per barge
Time in transit in automation mode (total)	Efficiency	Per barge
Number of trips taken	Efficiency	Per barge
Time in transit in automation mode (average)	Efficiency	Per barge
Time idle awaiting loading of cargo (static stop point at barge)	Efficiency	Per barge
Time idle awaiting unloading of cargo (dynamic stop point at barge)	Efficiency	Per barge
Time idle in queue (static stop points behind other ADS)	Efficiency	Per barge
Software errors establishing connectivity	Efficiency	Per barge
Software errors establishing automation	Efficiency	Per barge

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[1] Rail Safety Improvement Act, 49 U.S.C. § 20101 (2008). https://www.congress.gov/110/plaws/publ432/PLAW-110publ432.pdf

[2] Alaska Railroad Corporation. (2020). *Alaska Railroad Corporation Load Manual*. www.alaskarailroad.com

[3] Alaska Marine Lines. (n.d.). *Marine Equipment – Whittier Provider*. https://www.lynden.com/aml/resources/equipment/marine-equipment/whittier-provider/

[4] Alaska Department of Transportation and Public Facilities. (2023). *Whittier Weather*. https://dot.alaska.gov/creg/whittiertunnel/weather.shtml

[5] Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., & Hollnagel, E. (2003). Macrocognition. I*EEE intelligent systems, 18*(3), 81-85.

[6] Klein, G., & Wright, C. (2016). Macrocognition: from theory to toolbox. *Frontiers in psychology, 7,* 54.

[7] Whaley, A. M., Xing, J., Boring, R. L., Hendrickson, S. M. L., Joe, J. C., le Blanc, K. L., & Morrow, S. L. (2016). *Cognitive Basis for Human Reliability Analysis*. www.nrc.gov/reading-rm.html.

[8] Whaley, A. M., et. al., 2016.

[9] Liu, J., Zou, Y., Wang, W., Zhang, L., Qing, T., Zheng, T., & Ding, Q. (2021). A study on assigning performance shaping factors of the SPAR-H method for adequacy human reliability analysis of nuclear power plants. *International Journal of Industrial Ergonomics, 81*, 103051.

[10] Groth, K. M., & Mosleh, A. (2012). A data-informed PIF hierarchy for model-based human reliability analysis. Reliability Engineering and System Safety, 108, 154–174. https://doi.org/10.1016/j.ress.2012.08.006

[11] Kyriakidis, M., Kant, V., Amir, S., & Dang, V. N. (2018). Understanding human performance in sociotechnical systems – Steps towards a generic framework. *Safety Science, 107*, 202–215. https://doi.org/10.1016/J.SSCI.2017.07.008

[12] Klein, G., et. al. (2003).

[13] Whaley, A. M., et. al., 2016.

[14] Di Pasquale, V., Miranda, S., Iannone, R., & Riemma, S. (2015). A Simulator for Human Error Probability Analysis (SHERPA). *Reliability Engineering and System Safety, 139*, 17–32. https://doi.org/10.1016/j.ress.2015.02.003

[15] Hollnagel, E. (2012). *FRAM, the functional resonance analysis method: modelling complex socio-technical systems.* Ashgate Publishing, Ltd..

[16] Larouzee, J., & le Coze, J. C. (2020). Good and bad reasons: The Swiss cheese model and its critics. *Safety Science, 126*, 104660. https://doi.org/10.1016/J.SSCI.2020.104660

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[17] Whaley, A. M., et. al., 2016.

[18] Durso, F. T., Rawson, K. A., & Girotto, S. (2017). Comprehension and situation awareness. *Situational Awareness*, 77–107. https://doi.org/10.4324/9781315087924

[19] Klein, G., Phillips, J. K., Rall, E. L., & Peluso, D. A. (2007). A Data-Frame Theory of Sensemaking. In *Expertise Out of Context* (1st ed., pp. 113–155). Psychology Press.

[20] Lehto, M. R., & Nanda, G. (2021). Decision-making models, decision support, and problem solving. *Handbook of human factors and ergonomics,* 159-202.

[21] Kahneman, D. (2011). *Thinking, Fast and Slow.* Macmillan.

[22] Klein, G. (2008). Naturalistic decision-making. *Human factors, 50*(3), 456-460.

[23] Klein, G. (2008).

[24] Whaley, A. M., et. al., 2016.

[25] Reason, J. (1990). *Human Error*. Cambridge University Press.

[26] Whaley, A. M., et. al., 2016.

[27] Klein, G., et. al. 2003.

[28] Klein, G., et. al. 2016.

[xxix] Yin, G., & Yong, T. (2019, November). Comparison and analysis of positioning accuracy between DGPS and GPS. In Journal of Physics: Conference Series (Vol. 1345, No. 5, p. 052040). IOP Publishing.