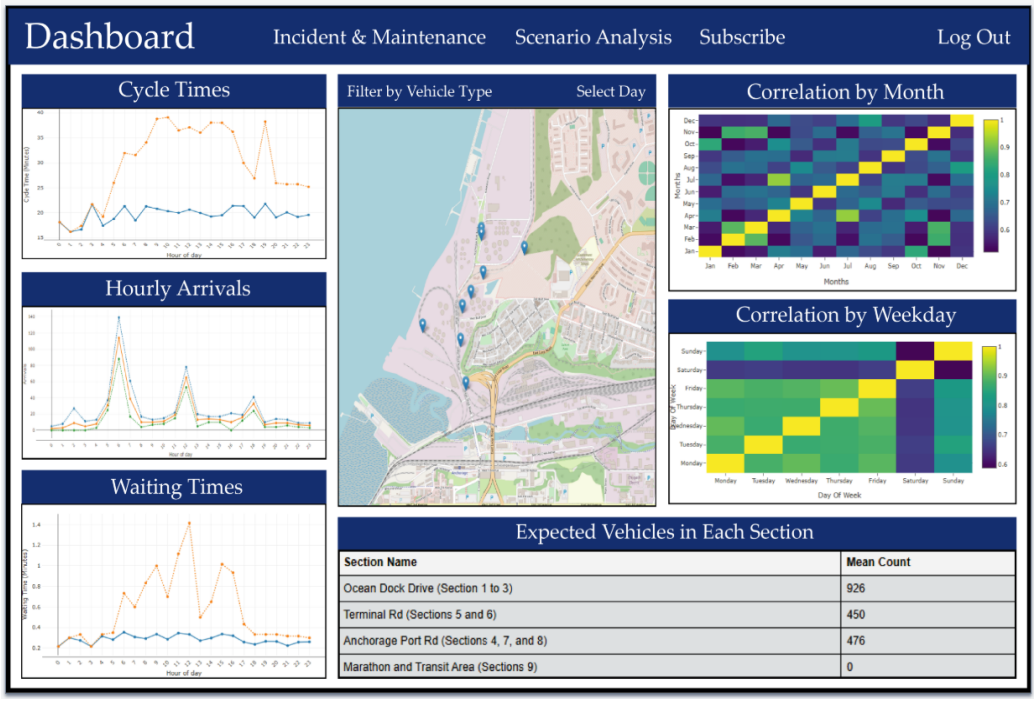
Research & Technology Transfer

Alaska Department of Transportation & Public Facilities

iFreightOps: A platform for Data-driven Freight Transportation Management in Port Operations



Prepared By:
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Report # FHWA-AK-4000(226)
June 2025

Prepared for:
Alaska Department of Transportation & Public Facilities
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

REPORT DOCUMENTATION PAGE

Form approved OMB No.

Public reporting for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-1833), Washington, DC 20503

1. AGENCY USE ONLY	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
Report # FHWA-AK-4000(226)	June 2025	Final Research Report: July 2023 – June 2025

4. TITLE AND SUBTITLE

Development of an intelligent truck transportation management application for freight and fuel movement through route optimization, scenario analysis, and incident management

5. FUNDING NUMBERS

State project # HFHWY00312
Federal project # 4000(226)

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

State of Alaska, Alaska Dept. of Transportation and Public Facilities Research and Technology Transfer
3132 Channel Drive
Juneau, AK 99801-7898

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

FHWA-AK-4000(226)

11. SUPPLEMENTARY NOTES

Performed in cooperation with Port of Alaska

12a. DISTRIBUTION / AVAILABILITY STATEMENT

No restrictions

12b. DISTRIBUTION CODE

N/A

13. ABSTRACT (Maximum 200 words)

Although marine ports frequently face landside congestion events that impact efficiency, current port management systems often lack comprehensive data-driven solutions for disruption prevention, timely intervention, and effective communication. To address this gap, this study presents iFreightOps, an integrated, cloud-based analytics and communication platform designed for proactive and reactive congestion management at ports. iFreightOps includes three core modules: (i) a Dynamic Traffic Dashboard for real-time monitoring and forecasting of key indicators such as truck arrivals, waiting times, and cycle times; (ii) a Scenario Analysis module that employs simulation modeling to evaluate alternative operational and infrastructural strategies under various disruption scenarios; and (iii) an Incident Management module with automated alerts and incident logging to support stakeholder response and future decision-making. The platform has been conceptually designed and experimentally evaluated using data and operational constraints reflective of the Port of Alaska, including gate constraints, railway disruptions, and infrastructure limitations. Numerical experiments indicate that iFreightOps can significantly reduce vehicle waiting times during short-term disruptions, with reductions of up to threefold observed in select scenarios through optimized rerouting strategies. Under typical operating conditions, redirecting peak-time traffic to alternative routes resulted in reductions of average waiting and cycle times by 25% and 15%, respectively.

14- KEYWORDS : Intelligent Transportation System, Port Landside Congestion, Disruption Management, Scenario Analysis, Port Traffic Dashboard, Port Communication Portal

15. NUMBER OF PAGES

55

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	N/A

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Acknowledgements

The research reported herein was performed under the FY23 STIC Innovation Incentive projects sponsored by the Alaska Department of Transportation and Public Facilities (AKDOT&PF) and conducted by the University of Missouri.

Sharan Srinivas, Associate Professor in the Department of Industrial & Systems Engineering, served as the Principal Investigator. Suchithra Rajendran, Associate Professor in the Department of Industrial & Systems Engineering, and Prasad Calyam, Curators' Distinguished Professor in the Department of Electrical Engineering and Computer Science, served as Co-Investigators.

Graduate students employed as research assistants included Nima Raad, Ray Wood, and Matt Floyd from the Department of Industrial & Systems Engineering, and Kiran Neupane, Hemanth Yeddulapalli, Karan Karthik, and Vamsi Pusapati from the Department of Electrical Engineering and Computer Science.

The research team gratefully acknowledges the contributions of Steve Ribuffo, Port Director at the Port of Alaska, who served as the primary liaison and facilitated engagement with key stakeholders, including representatives from trucking companies, shipping carriers, the information technology office, and port security.

The project also benefited from the support and guidance of Cristina Demattio, Research Program Manager, and Anna Bosin, P.E., Central Region Traffic & Safety Engineer, both with the Alaska Department of Transportation & Public Facilities (AKDOT&PF). Their assistance with project coordination, data acquisition, and stakeholder engagement was instrumental to this study.

Executive Summary

The Port of Alaska (PoA) in Anchorage serves as the primary entry point for nearly half of the state's inbound freight, handling over 545,000 container units annually and supplying essential goods to approximately 90% of Alaskans. Despite its critical role, PoA relies on a single entry and exit point via Ocean Dock Road, making landside truck operations vulnerable to traffic incidents, weather disruptions, and potential infrastructure projects such as rail realignment. This limited redundancy, coupled with minimal real-time visibility and informal incident communication with trucking partners, has created an urgent need for a resilient, data driven traffic management solution.

The primary goal of this Alaska STIC Innovation Project, initiated in collaboration with the Port of Alaska and jointly funded by FHWA and AKDOT&PF, was to develop *iFreightOps*, a cloud-based intelligent transportation system (ITS) platform to enhance landside freight mobility and operational resilience at PoA. The platform integrates the following key capabilities:

- Evaluation of internal and external detour routes to manage short- and long-term disruptions.
- Data-driven analytics to support day-to-day truck scheduling and long-term capital planning.
- Tools to improve incident response through timely alerts and accessible operational data.

iFreightOps is designed as a decision-support tool for transportation agencies and port stakeholders, providing real-time visibility, scenario-based planning, and structured communication to strengthen freight continuity and network resilience.

To assess the impact of disruptions and evaluate detour strategies, the study combined site visits, stakeholder interviews, and three years of weigh-in-motion data to build a high-fidelity discrete event simulation model. The baseline model, validated through stakeholder feedback, estimated an average truck cycle time of 24.5 minutes with minimal queuing under normal operating conditions. To test system resilience, 32 disruption scenarios were simulated across nine high-risk segments and twelve potential detour routes, reflecting variations in peak, off-peak, and annual freight volumes. Each detour was evaluated for operational efficiency, cost of implementation, and external constraints such as military access and community sensitivities. The simulation results highlight three critical insights for ensuring freight continuity at the Port of Alaska:

- **Redundancy is essential.** For each high-risk segment, at least one viable detour must be available. The absence of alternate routing can halt freight movement and disrupt statewide supply chains.
- **Internal low-cost detours offer significant coverage.** Routes such as the ABI and Marathon loops can effectively address eight of the nine identified disruption zones. The Military Base corridor offers full redundancy but is restricted to emergency use due to access protocols.
- **Operational impacts of selective detour use are modest.** The Military Base route increased average cycle time by only 4.8%, while the Marathon loop added 18.6%, an acceptable tradeoff during high-impact events.

These insights informed the design and functionality of *iFreightOps*, which consists of three integrated modules:

- A **Dynamic Traffic Dashboard** for near real-time forecasting of truck arrivals, queue lengths, and cycle times.
- A **Scenario Analysis Engine** for evaluating the impact of detours, infrastructure changes, and traffic policies.
- An **Incident Management Module** that issues customized alerts via SMS or email and maintains a searchable archive of historical incidents for performance review and process improvement.

Numerical experiments indicate that the use of *iFreightOps* during simulated short-term disruptions led to a threefold reduction in vehicle wait times. Under normal conditions, strategic traffic redirection through the platform yielded a 25% reduction in average queue lengths and a 15% reduction in cycle times. Stakeholder feedback confirmed the platform's usability and value.

Overall, this study demonstrates the value of integrating simulation, analytics, and communication into a unified decision-support platform. The recommended detour portfolio, combined with the *iFreightOps* platform, achieves the project's strategic objectives by safeguarding freight continuity, supporting capital planning, enabling proactive operations management, and improving incident response. The framework is readily transferable to other critical freight corridors in Alaska, such as the Seward and Glenn Highways, offering AKDOT&PF a scalable foundation for advancing smart, resilient freight infrastructure statewide.

1. INTRODUCTION AND RESEARCH APPROACH

1.1. Research Background

Ports play a critical role in the international logistics network by handling over 80% of the total global trade volume. In these dynamic hubs where massive amounts of cargo are processed daily, even minor congestion events can create ripple effects across supply chains and escalate into significant delays (Meersman et al., 2012). In the literature on port operations management, congestion events are classified as seaside or landside, based on where they take place. Seaside congestion refers to operational bottlenecks that occur on the maritime side, including vessel queues at anchorages, limited berth availability, and navigational channel constraints. In contrast, landside congestion emerges within port terminals and road networks, due to incidents, operational inefficiencies, or infrastructure limitations (Neagoe et al., 2021). Although both types of congestion can disrupt port operations, landside congestion is generally more critical due to a wider variety of risk factors, higher frequency, and direct impact on customers (Thennakoon et al., 2024). Landside congestion in ports can be classified into recurring and non-recurring, depending on their patterns of occurrence and underlying causes.

1.1.1. Landside Congestion: Typologies and Impacts

Recurring landside congestion occurs due to imbalances between supply and demand for transport infrastructure and happens regularly at specific times and locations (Motono, 2016). It is a predictable phenomenon resulting from factors such as limited terminal capacity, high truck arrival rates, and inefficient scheduling. Long truck queues forming every morning at port terminals, due to multiple trucking companies scheduling simultaneous deliveries, exemplify recurring congestion. On the other hand, non-recurring congestion is caused by unpredictable events such as adverse weather conditions, equipment failures, accidents, or sudden changes in demand. This type of congestion does not follow a set pattern and can be challenging to anticipate. While recurring congestion requires better coordination and long-term expansion plans, non-recurring congestion highlights the need for adaptive response strategies to mitigate disruptions (Verschuur et al., 2023). The significant financial and social impacts of landside congestion events require a proactive and reactive risk response plan that minimizes disruptions and enhances operational efficiency.

1.1.2. Role of Analytics in Supporting Operational and Strategic Decisions

Effective landside congestion management requires a layered approach that integrates real-time and historical data through descriptive, predictive, and prescriptive analytics. These tools enable port authorities to make both operational and strategic decisions that reduce delay and improve system reliability. Descriptive analytics provides visibility into traffic flow patterns, queuing behavior, and resource utilization by summarizing granular data such as truck arrivals, gate transactions, and terminal throughput (Pruyn et al., 2020). Predictive analytics builds on this foundation by forecasting congestion states and simulating the impacts of anticipated disruptions, enabling early warnings for high-risk scenarios. Prescriptive analytics leverages these forecasts to recommend optimal response strategies that adapt truck routing, yard allocation, or workforce scheduling, while also quantifying trade-offs and long-term benefits of alternative infrastructure investments.

Operational decisions supported by these analytics include dynamic truck sequencing, gate reallocation, and incident-based traffic control. Strategic decisions involve evaluating capital investments, revising terminal layouts, and designing detour plans that enhance network redundancy. Importantly, analytical tools allow ports to test both routine and stress scenarios, ensuring preparedness for recurring congestion and agility in the face of non-recurring disruptions.

1.1.3. Communication Systems in Port Operations

While analytical tools support proactive planning, effective management of non-recurring landside congestion also requires robust communication systems that enable timely and coordinated responses. The effectiveness of any response relies on how quickly stakeholders receive actionable information. A real-time incident notification system is essential for maintaining situational awareness during operational disruptions. Such a system must deliver accurate and concise information, such as the nature, location, severity, and anticipated duration of the disruption, along with recommended actions and safety protocols. To ensure coordinated response, the communication platform must serve a wide array of stakeholders, including terminal operators, shipping carriers, trucking companies, emergency responders, and public transportation agencies. Beyond real-time alerts, long-term operational learning depends on the preservation of structured incident records. A well-designed incident repository should log objective data (e.g., timestamps, queue impacts) and subjective insights (e.g., root causes, corrective actions, lessons learned). When integrated with analytical modules, these records enable continuous performance monitoring and refinement of operational protocols.

The integration of analytics and communication functions into a unified platform improves visibility, accelerates response, and enhances institutional learning. This forms the basis for the development of ***iFreightOps***, a cloud-based decision-support system designed to improve landside freight management at the Port of Alaska. Section 1.2 outlines the port's operational context and the motivation for this innovation effort.

1.2. Problem Statement and Research Motivation

1.2.1. Problem Description

The Port of Alaska in Anchorage plays a critical role in the state's economy, handling over 545,000 container units annually and serving approximately 90% of Alaska's population. Nearly half of the state's inbound freight flows through the port, making its operational resilience essential for ensuring the steady delivery of vital goods such as food and bottled water. Situated between the ocean, a military base (Joint Base Elmendorf-Richardson), and a residential area (Government Hill), the port faces significant geographical constraints that limit external routing options for freight traffic.

A key vulnerability in the port's current operations is its reliance on a single entry and exit gate along Ocean Dock Road. This single-gate constraint exposes the port to severe risks: disruptions caused by accidents, severe weather conditions, or future construction projects, such as the planned modernization of surrounding rail infrastructure, could immobilize landside freight movement entirely. Evaluating alternative internal and external access routes, such as the semi-developed corridors of Tract J, the Marathon route, and the Transit Area, represents an important step toward

enhancing operational resilience at the Port of Alaska. Each of these alternatives presents specific considerations involving feasibility, traffic flow, and community coordination. Recognizing these complexities, port stakeholders have expressed the need for a systematic, scenario-based approach to assess routing options under various disruption conditions. Applying data-driven methods to evaluate trade-offs and outcomes ensures infrastructure planning and operational decisions are both well-informed and aligned with long-term resiliency goals.

In addition to physical infrastructure, communication systems that support coordinated response and operational awareness are equally important. Current methods of disseminating incident updates, primarily through a general SMS system, offer limited capabilities for audience targeting, visual context, or supplemental information. These constraints can introduce challenges in the timely coordination of dispatching and scheduling activities. While regional traffic dashboards provide some visibility, stakeholders currently have limited access to live conditions within the port itself, which may affect responsiveness during congestion or unexpected disruptions.

To address these needs, this project proposes a comprehensive solution that integrates infrastructure planning with enhanced stakeholder communication. The key objectives are to:
(1) assess alternative routing options to improve resilience during disruptions; (2) evaluate the feasibility and operational effects of proposed improvements; (3) develop a real-time dashboard for internal traffic monitoring; and (4) implement a flexible, user-oriented communication platform to support timely and structured incident notifications. Together, these capabilities are intended to improve efficiency, reduce uncertainty, and support reliable freight movement through one of Alaska's most vital economic gateways.

1.2.2. Gaps in Existing Systems and the Need for iFreightOps

Although there is a growing body of literature on port risk management, queue estimation, and infrastructure planning, there remains a lack of fully integrated systems that combine advanced analytics and real-time communication within a single decision-support environment for congestion management (Jahangard et al., 2025). Existing commercial and in-house platforms often focus on isolated functions, such as appointment scheduling, incident alerting, or long-term capacity evaluation, without unifying these components into a cohesive, adaptive framework.

A key limitation in current systems is the absence of multi-layered analytics that blend descriptive, predictive, and prescriptive capabilities. This integration is essential for effective landside congestion management, particularly under dynamic and uncertain conditions. Scenario-based simulation tools, such as discrete-event or agent-based models, are rarely embedded into operational platforms, even though they are critical for evaluating both immediate disruptions and long-term planning options. In practice, many dashboards provide only static or descriptive views of traffic conditions, lacking the real-time forecasting or optimization functionalities needed for agile routing, gate operations, or resource allocation.

Additionally, the systematic capture of incident and maintenance records is often overlooked. Without a structured repository of disruption events, post-incident analysis remains limited, hindering efforts to institutionalize lessons learned and develop robust contingency procedures. This fragmentation across analytics, communication, and institutional knowledge restricts the ability of port operators to respond effectively to both recurring and non-recurring congestion.

These limitations underscore the need for an integrated, data-driven platform that combines real-time monitoring, advanced scenario analysis, and structured incident management. Addressing these gaps is central to developing resilient, efficient, and coordinated responses to landside congestion events at high-throughput logistics hubs such as the Port of Alaska.

1.3. Framework Overview and Research Contributions

To address the infrastructure vulnerabilities and communication challenges outlined in Sections 1.2.1 and 1.2.2, this study introduces iFreightOps, a cloud-based decision-support platform designed to improve landside freight operations at the Port of Alaska. The platform integrates real-time analytics, scenario-based planning, and structured stakeholder communication to enhance both proactive planning and reactive response capabilities.

iFreightOps is built around a three-module framework:

- ***Incident Management Module:*** Facilitates structured, timely reporting and dissemination of incident information to key stakeholders.
- ***Scenario Analysis Module:*** Supports strategic planning and operational preparedness through simulation of disruption scenarios and evaluation of alternative routing strategies.
- ***Traffic Dashboard Module:*** Provides predictive analytics and visualizations of port traffic patterns using historical and semi-real-time data.

This integrated platform contributes several innovations to port congestion management:

- ***Unified Multi-Layered Analytics***: Combines descriptive, predictive, and prescriptive analytics in a single system to support agile and informed decision-making.
- ***Simulation-Driven Scenario Evaluation***: Leverages discrete-event simulation to test and compare infrastructure or operational alternatives under varying demand and disruption conditions.
- ***Real-Time Operational Visibility***: Merges near real-time data with historical trends to forecast truck arrivals, cycle times, and queuing conditions.
- ***Targeted, Automated Alerting***: Delivers disruption notifications tailored to stakeholder roles, incident characteristics, and geographic areas.
- ***Port-Specific Customization***: Developed for the unique constraints and freight demands of the Port of Alaska, ensuring operational relevance.
- ***Interactive and User-Friendly Interface***: Enables rapid interpretation of system status and facilitates data-driven responses during dynamic conditions.

These contributions directly support the development of an integrated, resilient freight management framework. iFreightOps serves as a replicable model for similar logistics-critical environments where congestion and disruption risks must be managed in real time.

1.4. Research Methodology

This section presents the structured DMAIC-based methodology used to develop iFreightOps, a cloud-based platform for managing landside congestion at the Port of Alaska. The approach integrates system design, data analytics, and stakeholder engagement to ensure both technical robustness and operational relevance. Section 1.4.1 details the backend development, including discrete-event simulation, traffic forecasting, and automated incident data processing, capabilities that form the analytical core of the platform. Section 1.4.2 focuses on the frontend interface, which translates these backend outputs into decision-support tools. This includes a real-time traffic dashboard, a scenario analysis module, and an incident management system. Together, these components enable data-driven planning, proactive disruption response, and real-time communication, supporting resilient and efficient freight operations.

1.4.1. Core Engine Development: Simulation, Forecasting, and Incident Processing

The research methodology adopts a structured DMAIC (Define, Measure, Analyze, Improve, Control) framework to guide the backend development of iFreightOps, with an emphasis on integrating simulation, forecasting, and incident processing capabilities across the three core modules.

- **Define:** The research team identified the vulnerability of landside freight operations at the Port of Alaska, specifically the reliance on a single entry and exit point and the lack of an integrated incident response system. Three core backend functionalities were prioritized: high-fidelity simulation for scenario analysis, predictive analytics for traffic forecasting, and automated backend logic for incident processing and historical data archiving.
- **Measure:** Three years of historical Weigh-in-Motion (WIM) data, geo-referenced CAD maps, time study records, and stakeholder inputs were collected. These datasets informed arrival patterns, truck behaviors, processing times, and incident categories. The backend architecture integrated these inputs into the data pipelines used by the discrete-event simulation engine and predictive analytics models.
- **Analyze:** The team developed a 3D baseline simulation model in Simio and independently verified it using SimPy to ensure modeling accuracy. Operational baselines such as an average truck cycle time of 24.5 minutes were established. Concurrently, forecasting models were trained using historical traffic patterns to support near real-time predictions within the Traffic Dashboard. Common incident scenarios were also classified and analyzed for response latency and communication gaps, shaping the backend schema for incident handling.
- **Improve:** A total of 32 disruption scenarios were simulated to evaluate the performance of twelve detour routes across different demand levels. Backend algorithms were enhanced to support conditional routing logic and dynamic performance tracking. Predictive components were calibrated for short-term cycle time and queue forecasts. For incident management, templates for SMS/email notifications were automated, and structured fields for incident logging were introduced for consistency and traceability.
- **Control:** Backend modules were connected to a real-time data ingestion pipeline with a quarterly refresh protocol for WIM data and infrastructure updates. The simulation model and predictive analytics were embedded within the backend to drive the Scenario Analysis and Traffic Dashboard modules. For the Incident Management module, a structured database was implemented to retain incident history, root causes, and resolution timelines, enabling retrospective analysis and institutional learning.

1.4.2. User Interface Design: Dashboard, Alerts, and Scenario Evaluation

The front-end development of iFreightOps focused on building an interactive, user-centered interface that seamlessly integrates the core analytics modules with stakeholder communication features. The architecture is modular and cloud-native, employing Flask for backend services, React for dynamic user interfaces, and MongoDB for secure data management. The interface was designed through an iterative process informed by stakeholder feedback and usability evaluations. The dashboard provides clear visualization of operational forecasts, system status, and simulation outputs. It also enables users to run custom what-if scenarios and view resulting impacts on port congestion metrics.

The Scenario Analysis module presents a flexible menu of disruption cases, allowing users to simulate and compare mitigation strategies before implementation. Users can configure simulation parameters, select routing options, and evaluate trade-offs using visual output summaries and downloadable reports. The Traffic Dashboard synthesizes historical and forecasted data to support day-to-day scheduling, with graphical indicators for queue lengths, arrival rates, and average turnaround times. Filters enable users to examine trends by time of day, season, or traffic condition. The Incident Management module enables real-time communication through SMS and email alerts. It allows users to issue structured notifications with embedded location, time, and recommended action tags. All incident records are stored in a searchable log that facilitates post-incident reviews and continuous improvement.

This front-end layer ensures that the analytical capabilities developed in the backend are actionable, intuitive, and tailored to the needs of decision-makers across transportation agencies and port operations.

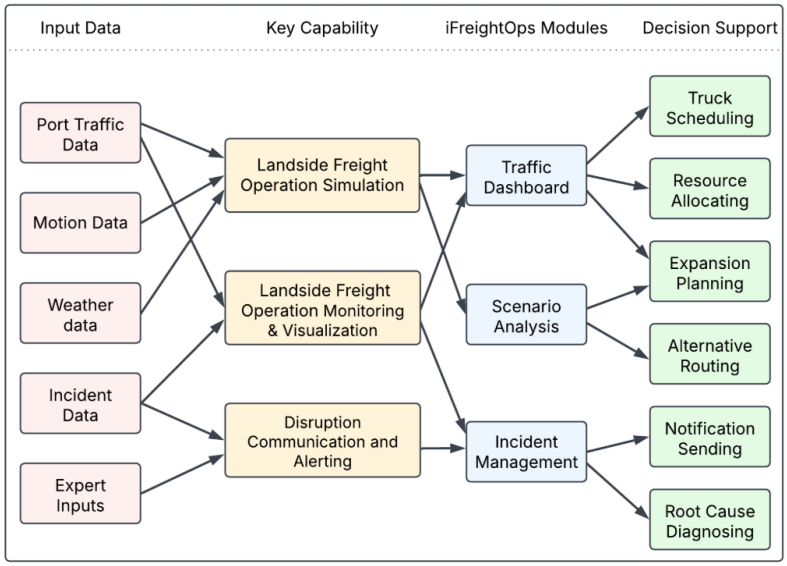


Figure 1: Overview of iFreightOps Capabilities

Figure 1 illustrates the relationships among the various data sources, the core analytical capabilities, the integrated functional modules, and the specific operational and strategic decision-making outcomes enabled by the platform. Specifically, the figure highlights how each input data source contributes directly to specific key analytical capabilities. Port traffic, motion, and weather

data are primarily utilized in the Operation Simulation and Visualization capabilities, which support the Traffic Dashboard and Scenario Analysis analytical modules. Incident data and expert inputs primarily support the Communication and Alerting capability, which is crucial for the Incident Management module. Furthermore, the visualization delineates how the outputs of these capabilities translate into concrete decision support outcomes such as truck scheduling, resource allocation, expansion planning, alternative routing, notification sending, and root cause diagnosis.

2. FINDINGS

This section contextualizes the study's contributions through a review of relevant literature, identifying key gaps that motivate the need for an integrated, analytics-driven decision-support platform. The subsequent analysis presents a structured workflow, spanning data acquisition, model calibration, and disruption evaluation, that enables stakeholders to assess the operational consequences of alternative strategies. The findings validate the platform's relevance in supporting infrastructure investments and ensuring robust port operations.

2.1. State-of-the-Art Summary

This subsection reviews current research and operational practices related to landside port congestion, highlighting interventions that improve resilience and mitigate disruption impacts. It emphasizes three foundational themes: (1) classification and root causes of congestion events, (2) simulation-based evaluation of infrastructure and operational strategies, and (3) the role of stakeholder communication in incident management. By identifying common approaches and unresolved limitations in the literature, this review establishes the analytical and practical basis for the development of the iFreightOps platform.

2.1.1. Landside Port Congestion Factors and Solutions

Port landside congestion is the buildup of cargo-handling vehicles inside the internal road network and gate complexes of a port, which slows the container delivery process and related terminal activities. Landside congestion events undermine supply chain resilience and competitiveness, drive up costs, and add operational uncertainty for all stakeholders. Because the underlying causes involve intertwined social, technical, and behavioral factors and no single remedy fits every situation, researchers worldwide have developed case-specific congestion management strategies that reflect the unique context and needs of each port (Neagoe et al., 2021).

Some studies focus on identifying and categorizing the causes of landside congestion in ports. Neagoe et al. (2021) utilized a grounded theory-based coding approach across multiple case studies to identify seven key factors contributing to congestion at bulk cargo port terminals. These factors include infrastructure limitations, interdependence of operations, operational disruptions, limited coordination, misaligned incentives, low supply chain flexibility, and performance expectations. Their research highlights that congestion is a context-dependent issue primarily influenced by behavioral and coordination challenges rather than infrastructure alone (Neagoe et al., 2021). Motono et al. (2016) identified trailers with improper documents as a key cause of landside gate congestion in ports. Using queuing theory and discrete-event simulation, they showed that these vehicles significantly increase service times and therefore congestion levels. Eddrgash (2022) conducted a systematic literature review and an online survey supported by exploratory factor analysis (EFA) to identify internal and external causes of landside port congestion. They

categorized these causes into five main groups: technical, economic, policy, social, and natural, and concluded that mismanagement and infrastructural limitations are among the most dominant triggers of landside congestion. Their research emphasizes the need for coordinated action across all maritime logistics stakeholders, including port authorities, trucking firms, customs, and regulatory bodies, to mitigate congestion risks effectively (Eddrgash, 2022).

While the literature addressing landside congestion remains sparse, the available studies highlight the operational need for unified, data-informed, and collaborative mitigation frameworks. One of the most widely advocated approaches is the implementation of integrated information systems to enhance real-time decision-making and coordination among key stakeholders, including port authorities, customs, and transport companies (Neagoe et al., 2017). Another structural intervention involves port expansion plans, which aim to decentralize operations and relieve pressure on port gate infrastructure (Rathnayake and Wijeratne, 2015). Complementing these infrastructural efforts, simulation modeling is often employed to test various management scenarios related to gate assignment and resource utilization (Liu et al., 2023). Several ports have also implemented truck appointment systems to manage truck arrivals and efficiently minimize terminal congestion; these systems are typically driven by traffic data and aim to distribute truck flow more evenly throughout the day, thereby preventing peak-time bottlenecks (Xu et al., 2021). More recently, modern technologies such as GPS and IoT have been used to detect congestion hotspots and support dynamic traffic management (Thennakoon et al., 2024). At the tactical level, studies suggest optimizing gate allocation using micro-scenario modeling to better align capacity with demand (Chuchottaworn et al., 2024). Finally, effective congestion mitigation appears to require reforms in institutional coordination mechanisms to address both physical and behavioral bottlenecks (Eddrgash, 2022).

2.1.2. Simulation-Based Evaluation of Landside Congestion Mitigation Strategies

Although various methods, including system dynamics (Lin, 2022), queueing theory (Roy, 2022), Bayesian networks (Yin, 2024), and statistical analyses (Svanberg, 2021) have been employed in the literature to assess risks leading to landside congestion and to evaluate mitigation or counteractive measures, simulation-based analyses remain the most widely used approach. These models are applied both at the operational level, to respond to non-recurring congestion events, and at the strategic level, to test long-term solutions to prevent recurring congestion occurrences.

Simulation models have been predominantly used to identify landside congestion spots by analyzing vehicle flows and gate operations. Torrisi et al. (2025) used a traffic simulation model to analyze congestion at the port-city interface of the Port of Catania. By modeling interactions between urban traffic and port operations under various demand and supply scenarios, they identified the key bottlenecks (Torrisi, 2025). Neagoe et al. (2021) employed discrete-event simulation (DES) to model truck turnaround times using truck weighbridge and geo-positioning data (Neagoe, 2021). Their findings demonstrated that optimizing gate processes and appointment systems could substantially reduce queue lengths. Li et al. (2016) integrated traffic-flow modeling with DES to account for external road networks and internal terminal loops. Their results show that driver behavior significantly affects landside throughput (Li, 2016). Kulkarni et al. (2017) proposed a simulation-optimization framework that focuses on efficient gate operations in a multipurpose port setting. Their work tackles the outbound gate system, modeled as a multi-class, multi-lane queuing system (Kulkarni, 2017). By integrating a DES model with an optimization

component, they identified effective lane-management policies to balance reduced lane operating hours against acceptable waiting times. Similarly, Wang et al. (2022) developed a DES-based queuing model to evaluate an alternative gate policy that allows trucks with appointments to switch to walk-in lanes if the TAS lanes are fully occupied (Wang, 2022). Their stationary two-class queuing strategy demonstrated that such switching policies can significantly reduce truck waiting times, especially under high TAS lane utilization. Rajamanickam and Ramadurai (2015) applied a micro-simulation approach in VISSIM for Chennai Port to study the influence of geometric configurations on truck congestion (Rajamanickam, 2015). Their scenarios, such as introducing alternate entry roads and staggered checkpoints, demonstrated how detailed modeling of individual vehicle movements can lead to targeted infrastructure solutions. More recently, Carboni et al. (2024) applied a microscopic traffic simulation model to evaluate internal and external vehicle flows within container terminals. By incorporating an emissions component, their approach provided a decision-support tool that improves operational efficiency and sustainability under disruption scenarios (Carboni, 2024).

Simulation models have also been employed for port expansion planning to mitigate recurring landside congestion. These models are decision-support tools to evaluate future infrastructure needs and resource configurations under growing demand scenarios. For instance, Cimpeanu et al. (2017) developed a comprehensive simulation framework to support long-term investment decisions at a European port (Cimpeanu, 2017). Their model captures bulk carrier arrivals, unloading, transport, and storage times while accounting for stochastic weather delays. By analyzing different scenarios for infrastructure upgrades, the model assesses the impacts on key performance indicators, including costs and queueing delays. Also, Triska et al. (2020) developed a DES model to evaluate how alternative configurations of yards and gates influence terminal throughput and resource allocation decisions (Triska, 2020). Sadeghi et al. (2021) developed a simulation model in AnyLogic to identify bottlenecks and evaluate proposed improvements for a port's rail container terminal. Using real operational data from over 19 000 container movements, the study demonstrated that the suggested strategies could reduce handling time and costs by up to 20% without requiring infrastructure investment. Their study extends the role of simulation in landside congestion management to multimodal settings (Sadeghi, 2021).

2.1.3. Role of Communication in Port Disruption Readiness

The role of communication systems in port disruption management has garnered increasing attention in recent literature, particularly in the context of resilience enhancement. Nagi et al. (2021) conducted a community analysis at the Port of Hamburg and found that digital platforms that facilitate integrated data exchange and predictive analytics improve coordinated risk governance. Xu et al. (2021) demonstrate that real-time data sharing, multi-stakeholder coordination, and modern communication infrastructures are essential governance mechanisms for alleviating container-port congestion. He et al. (2023) argue that improved communication channels among port actors significantly enhance agility and shorten recovery cycles following supply-chain shocks, especially when coupled with technological innovation. Hald and Coslugeanu (2022) further highlight that timely information dissemination across the supply network facilitates more effective responses to disruptions. Similarly, Wang et al. (2023) emphasize that active communication and information exchange, both internally among port personnel and externally with regulatory and meteorological agencies, are crucial for mitigating disruption impacts. They identify internal communication, such as timely updates on shift

schedules and equipment operations, as a core strategy for strengthening response capacity through improved coordination and situational awareness. Building on this, González et al. (2024) propose a multi-stage framework for evaluating port-resilience strategies, identifying communication protocols and remote data accessibility as key components of adaptive capacity. Moreover, Cerin et al. (2024) establish that the integration of advanced artificial intelligence into port communication systems can optimize operational performance, reduce congestion, and lower emissions in complex port environments.

2.1.4. Gaps in Integrated Decision-Support Platforms and Research Contributions

Although prior work has made significant progress in addressing isolated aspects of landside congestion, key limitations remain in developing an integrated decision-support environment tailored for ports. These limitations span across simulation-based analysis, predictive modeling, and stakeholder coordination. First, existing systems tend to focus on a narrow scope, either simulation modeling for infrastructure planning, descriptive dashboards for traffic visualization, or communication tools for incident alerts. Few platforms synthesize these functions into a unified architecture that supports simultaneous strategic planning and operational response. This limits the ability to evaluate complex trade-offs under dynamic disruption scenarios. Second, most simulation studies in the literature are not operationalized into tools accessible to decision-makers. High-fidelity models often remain standalone research artifacts rather than embedded components of user-facing platforms. As a result, there is limited continuity between analytical outputs and real-world decision workflows, particularly during time-sensitive disruptions. Third, current communication infrastructures rarely incorporate analytics or scenario intelligence into the information flow. Existing platforms typically push static notifications without context on operational implications. This constrains situational awareness and diminishes the ability of stakeholders to coordinate effective responses based on data-informed forecasts or performance projections. To address these gaps, the iFreightOps platform integrates three essential modules, Simulation and Scenario Analysis, Predictive Traffic Dashboard, and Incident Management, into a single cloud-based system. The platform enables stakeholders to evaluate short- and long-term disruption strategies, monitor traffic in near real-time, and coordinate response efforts through structured communication tools. These capabilities bridge the gap between analytical insights and operational decisions, enhancing the resilience of port logistics through improved foresight, responsiveness, and coordination.

2.2. System Description: Landside Truck Operations at the Port of Alaska

The Port of Alaska supports continuous freight movement through its landside access network, which handles substantial volumes of truck traffic on a 24/7 basis. The port's internal circulation system is accessed via two principal routes: West Loop Road, connecting to downtown Anchorage, and Ocean Dock Road, which services traffic from regional trucking hubs. These access roads converge just before the Security Checkpoint, after which all inbound and outbound truck movements rely on a single arterial route, making the system highly sensitive to disruptions (Figures 2 and 3).

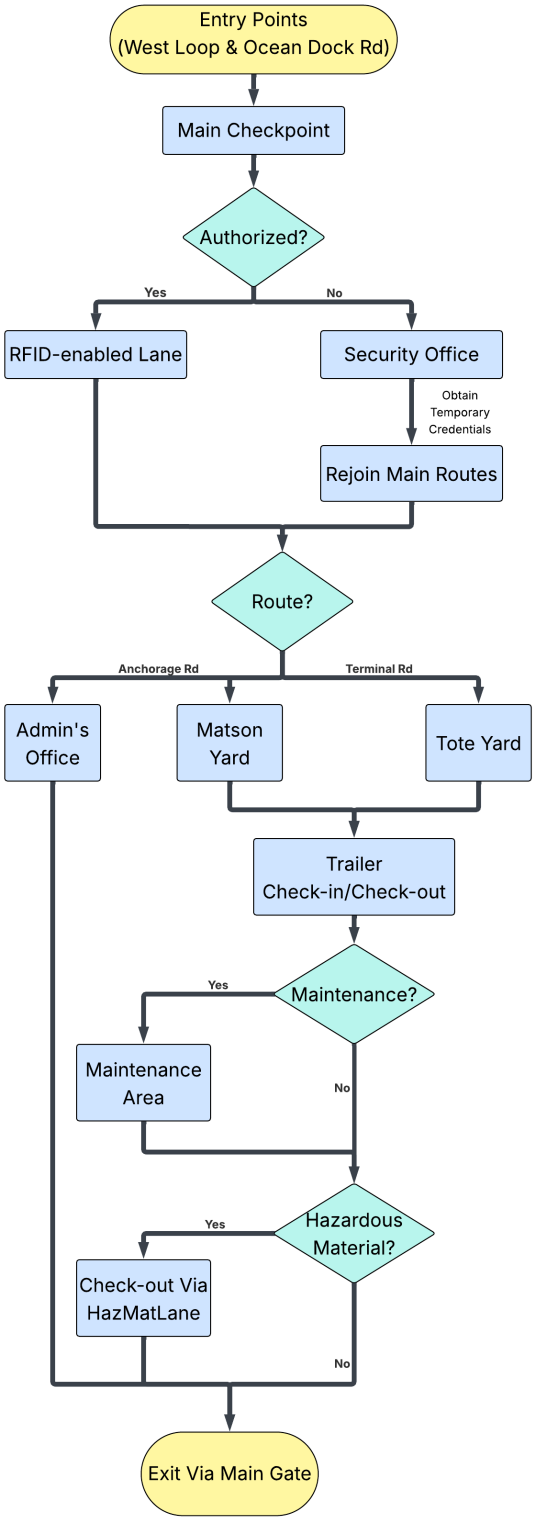


Figure 2: Vehicle Movement Flowchart at Port of Alaska

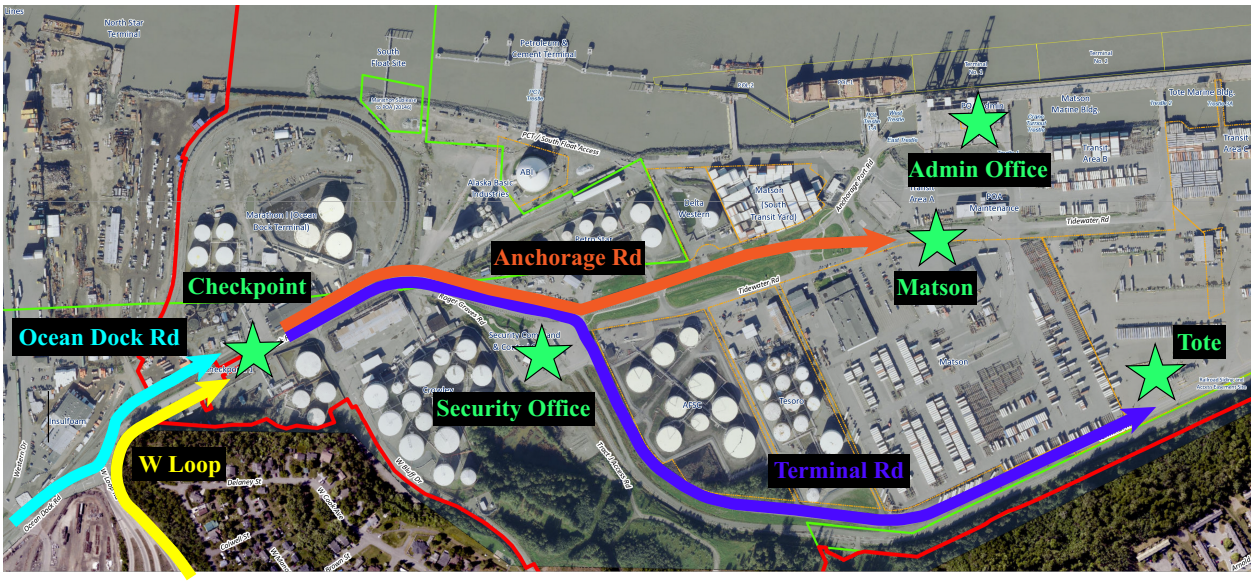


Figure 3: Traffic Routes Leading to the Port Gate and Extending to Container Yards

All vehicles entering the port are subject to a Security Checkpoint. Authorized freight trucks and port employee vehicles are granted expedited entry via RFID-enabled access passes. Visitors and non-authorized vehicles must present identification and state their purpose. Those lacking prior authorization are directed to the Security Office, accessible via Roger Graves Road, to obtain temporary credentials. After clearance, these vehicles rejoin the internal port circulation system, typically using Terminal Road or Ocean Dock Road. Truck traffic at the port exhibits distinct peak and off-peak periods, influenced by vessel schedules, trucking company dispatch times, and gate operations. The majority of freight vehicles, including approximately 95% of truck traffic, proceed beyond the checkpoint and transition from Ocean Dock Road to Anchorage Port Road, which intersects Terminal Road. This intersection serves as the primary internal routing node, directing vehicles toward the two principal maritime shipping companies operating within the port. Employee vehicles also utilize this network to reach administrative facilities and designated parking areas. Additional traffic diverges earlier to access specific terminals, such as Marathon and Crowley, via short turn-offs along Ocean Dock Road and East Bluff Drive. Within the freight yards, trucks undergo a structured check-in and check-out process, documenting trailer IDs for inbound and outbound movements. Some trucks may also be routed to an on-site maintenance facility if equipment issues are detected. Furthermore, loads containing hazardous materials (HazMat) are required to exit through a dedicated HazMat Lane, in compliance with regulatory protocols. For the purposes of this study, it is assumed that all vehicles exit the port along the same route used for entry. This assumption is consistent with observed routing patterns and supports the structure of the simulation model developed in this analysis.

2.3. Data Collection and Analysis

To analyze temporal patterns in landside truck arrivals at the Port of Alaska, the study utilized multiple data sources, with primary reliance on weigh-in-motion (WIM) sensor data collected by the AKDOT&PF. A WIM sensor is strategically positioned along the sole access road prior to the Security Checkpoint, capturing every inbound and outbound vehicle entering the port premises. These sensors automatically record detailed attributes of each vehicle, including timestamp, gross

vehicle weight, speed, and axle configuration. For the purposes of this study, WIM records spanning a three-year period, beginning shortly after the lifting of initial COVID-19 restrictions, were extracted from the AKDOT&PF public WIM database. The dataset enabled disaggregation of vehicle entries into passenger cars and freight trucks, allowing for a refined analysis of traffic composition. Temporal trends were then assessed to identify systematic variations in truck arrivals across different hours of the day, days of the week, and months of the year. The results revealed distinct peak and off-peak periods, underscoring the importance of time-of-day-specific modeling in subsequent simulation and scenario analyses. Figure 4 presents a snapshot of monthly traffic profiles obtained from WIM data for cars and trucks.

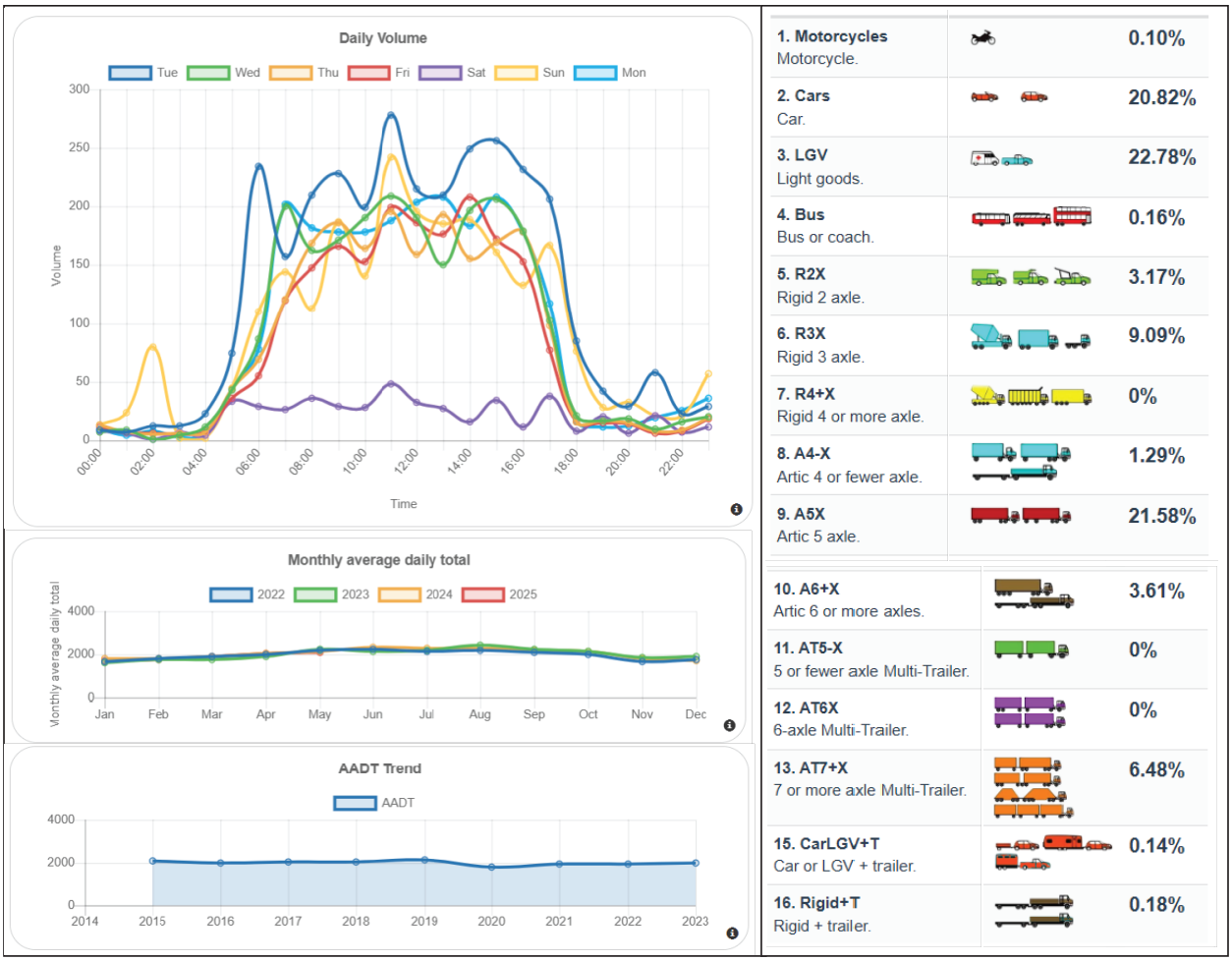


Figure 4: Monthly WIM Data Snapshot (May 2025)

2.4. Modeling and Analysis of Port Landside Freight Operations

2.4.1. Representation of Baseline Freight Operations During Normal Conditions

The baseline representation of landside freight operations at the Port of Alaska was developed using discrete-event simulation modeling to capture the typical flow of trucks and vehicles under regular operating conditions. A detailed and scaled map provided by port authorities served as the spatial foundation for modeling vehicle movements, decision points, and service nodes. The

system includes two primary vehicle types: Trucks, representing freight operations, and Cars, representing all other vehicular activity, including employee and visitor traffic. Although both types are modeled to capture realistic traffic dynamics, only Truck entities are used for performance evaluation.

Historical arrival rates were derived from three years of weigh-in-motion (WIM) data collected by AKDOT&PF. The data was aggregated by hour, day of week, and month to capture temporal patterns in vehicle flow. For each hourly period in the simulation, average truck and car arrivals were computed and randomly distributed within the hour. Entrances were then probabilistically split between W Loop Rd and Ocean Dock Rd. Processing times for various activities, such as security checks, freight yard operations, and HazMat inspection, were modeled using triangular distributions based on time studies and stakeholder surveys. Additional decision logic captured operational branching, including maintenance requirements for outbound trailers and routing based on freight company destinations.

The model was developed using Simio due to its support for custom routing logic and 3D spatial visualization. Entities were routed through sources, servers, and transfer nodes placed on the scaled port map, with paths representing key road segments such as Ocean Dock Rd, Terminal Rd, and Anchorage Port Rd. The layout captures stop points including security checkpoints, maintenance facilities, employee parking areas, and freight yards. This baseline model enables quantification of key performance indicators such as truck cycle time, queue lengths, and resource utilization under standard conditions. It provides the analytical foundation for disruption scenario evaluation and strategic planning addressed in subsequent sections.

2.4.2. Scenario-Based Analysis of Long-Term Disruption Impacts

Planned infrastructure improvements, including rail realignment and facility upgrades associated with the Port Modernization Project, present new operational uncertainties for the Port of Alaska's landside freight network. To proactively assess the impact of such developments, a series of disruption scenarios is simulated to evaluate potential routing alternatives and their effectiveness in preserving system performance during prolonged construction activities or access limitations.

The freight corridors serving the port intersect with three key railroad crossings: (i) before the Security Checkpoint along the main entry road, (ii) near the intersection of Roger Graves Road and Anchorage Port Road, and (iii) along Terminal Road near its intersection with Anchorage Port Road. These crossings serve as critical nodes in the system. Disruptions at any of these points may significantly constrain access to major freight yards and reduce system throughput. Figure 5 highlights the geographic placement of these three crossings within the internal road network. To evaluate operational resilience under such conditions, a scenario-based simulation approach is employed. Each disruption scenario represents either a planned closure due to construction or an unplanned event such as an accident. The simulation model is adjusted to reflect the segment-specific inaccessibility, enabling detailed analysis of alternate routing configurations.

The evaluation focuses on two core dimensions: operational performance and implementation feasibility. Operational metrics include average truck cycle time, total system delay, and queue lengths at key checkpoints. Feasibility factors encompass route readiness, estimated reactivation costs, institutional constraints (e.g., military access or community restrictions), and the level of

internal stakeholder coordination required. Alternative routing strategies are classified as internal or external detours, depending on whether they traverse within the port boundary or rely on auxiliary access points. Each alternative is assessed not only for its ability to bypass disrupted segments but also for its potential to preserve acceptable service levels during prolonged outages. This structured scenario analysis informs contingency planning by quantifying the trade-offs associated with each detour and identifying a portfolio of resilient routing strategies. The resulting recommendations guide port operators in allocating resources, sequencing mitigation actions, and prioritizing infrastructure investments to strengthen overall freight continuity.

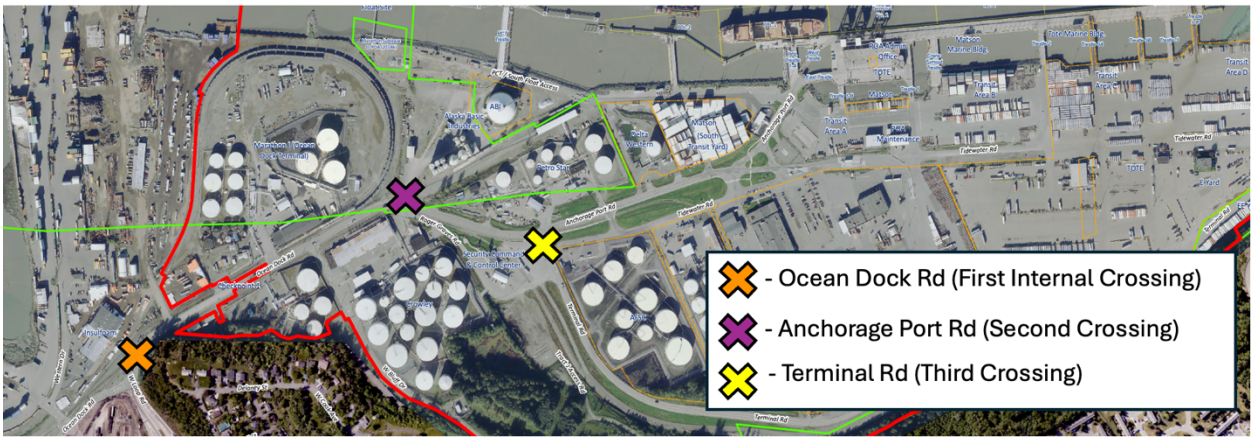


Figure 5: Rail-Road Crossings at the Port of Alaska.

2.4.3. Short-term Disruption Scenario Analysis

To support rapid response during unplanned operational interruptions, a structured classification of short-term disruptions is conducted based solely on their spatial location within the port's internal road network. These disruptions, such as traffic accidents, localized equipment failures, or weather-related blockages, can significantly hinder truck mobility and require immediate, location-specific rerouting strategies.

Recognizing that the impact of disruptions and viable bypass options vary depending on where they occur, the port's landside freight network is systematically segmented into nine operationally distinct zones. Each zone corresponds to a critical segment of the internal freight corridor and is associated with a tailored set of detour options. This location-based segmentation ensures that, for any given disruption, port personnel can promptly identify and activate context-specific routing alternatives to maintain continuity of freight operations. For instance, a disruption near the first rail crossing can be mitigated by diverting traffic through Insulfoam, West Bluff Drive, the Military Base route, or Tract J. In contrast, blockages near the third rail crossing require alternate paths such as Transit Area A, Roger Graves Road, or segments of Anchorage Port Road. Each of these detour routes offers differing degrees of accessibility and operational suitability depending on the disruption site.

By codifying these spatial dependencies, the nine-section segmentation serves as the foundation for real-time disruption response. It enables pre-positioning of detour protocols, facilitates rapid situational assessment, and ensures that all critical nodes within the port remain connected through redundant routing paths. Figure 6 illustrates the nine distinct segments of the port's internal road network along with their associated detour options.

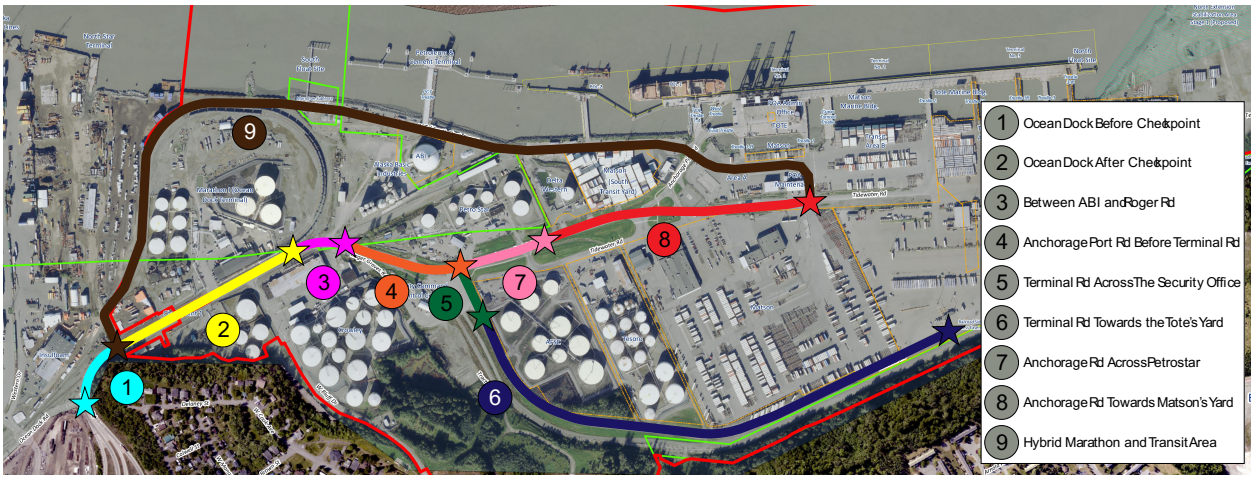


Figure 6: Port of Alaska internal freight network with nine alternative routing sections.

2.4.4. Routing Alternatives for Disruption Mitigation

Effective disruption response at the Port of Alaska requires a well-defined inventory of routing alternatives that can be deployed to preserve operational continuity. Due to the port's geographic and jurisdictional constraints, viable rerouting options are limited and must be carefully evaluated for both feasibility and performance impact.

The Port of Alaska is situated northwest of downtown Anchorage along the Knik Arm of the Gulf of Alaska. It is bordered to the west by coastal waters, to the north by the Elmendorf-Richardson Joint Base, and to the east by steep terrain and the residential Government Hill neighborhood. These geographic and institutional boundaries limit the availability of continuous external bypass corridors. Although an emergency-access route exists through the military base, it is not designed for sustained freight use. Similarly, prior engagements with the Government Hill community have indicated resistance to permitting long-term truck traffic through the area. The surrounding terrain also presents significant physical limitations to road expansion, reducing the feasibility of constructing high-capacity external links. Given these constraints, the port must primarily rely on internal alternative routes to mitigate blockages and maintain landside freight movement. All known and potential internal and external routes were reviewed in the current analysis. An updated aerial map provided by port authorities was used to confirm topological accuracy and ensure no recent infrastructure changes would invalidate routing assumptions.

The evaluation process considered each route's physical suitability for two-way freight traffic, current access permissions, and proximity to critical freight corridors. While some routes are presently operational and can be activated on short notice, others would require upgrades or interagency coordination to be considered viable. This inclusive approach enables port management to assess a wide range of scenarios and develop proactive contingency plans. Each candidate route is described below, along with the internal segments it can support during a disruption. These alternatives are later evaluated based on their operational feasibility.

Alternative Route 1: Insulfoam Corridor Detour

This detour route provides an internal bypass around the first major railroad crossing located along Ocean Dock Road, near the intersection with W Loop Road. The corridor passes through the lot

adjacent to the Insulfoam facility, a satellite site of a national plastic manufacturing company. The detour begins by turning south on Ocean Dock Road, away from the main port entrance, and crossing the railroad tracks onto Western Drive. Vehicles then navigate through the Insulfoam lot, bypassing the east side of the building, and reconnect with Ocean Dock Road past the typical entry congestion points. This corridor serves as a short internal bypass that circumvents disruptions along the initial segment of Ocean Dock Road, including the first railroad crossing and the approach to the Security Checkpoint. Figure 7 illustrates the proposed bypass route and the baseline segments it offsets, enabling continued access into the port when blockages occur near the main entry alignment.



Figure 7: Proposed Insulfoam Route.

Alternative Route 2: Marathon Terminal Bypass

This detour route leverages the internal loop around the Marathon terminal, situated west of Ocean Dock Road. It begins at the intersection of Ocean Dock Road and the first outer road, loops around the Marathon facility, and proceeds along South Float Access Road. The route then passes between the Delta Western and Petro Star terminals before reconnecting with Anchorage Port Road, allowing vehicles to resume the standard freight route. This bypass facilitates continued operations in the event of blockages along Ocean Dock Road after the outer road intersection, including the second railroad crossing and the initial segment of Anchorage Port Road. As the route lies within the secured perimeter, no additional checkpoint adjustments are required. Figure 8 illustrates the Marathon corridor detour and the baseline segments it is designed to bypass.



Figure 8: Proposed Marathon Route.

Alternative Route 3: Bypass via ABI Corridor

This detour utilizes the internal road through the Alaska Basic Industries (ABI) terminal, which is situated north of the Marathon facility within the secured area of the Port of Alaska. The route begins at the intersection of Ocean Dock Road and the outer road leading into the ABI terminal. Vehicles proceed through the ABI terminal and continue along South Float Access Road, paralleling the waterfront. The detour then follows the same path as the Marathon route, turning between the Delta Western and Petro Star terminals before reconnecting with Anchorage Port Road to resume standard operations. The ABI corridor bypasses key segments of Ocean Dock Road and Anchorage Port Road affected by the second railroad crossing, with the exception of the portion between the first outer road and the ABI access point. As the entire route lies within the secured perimeter, it does not require adjustments to the existing security checkpoint infrastructure. This makes it a viable alternative to the Marathon route in scenarios where routing flexibility or feasibility constraints arise. Figure 9 depicts the ABI corridor detour and the corresponding baseline segments it circumvents.



Figure 9: Proposed ABI Route.

Alternative Route 4: Military Base Corridor Detour

This routing option leverages Dena'ina Road (also known as Haul Road), which connects the Port of Alaska to Joint Base Elmendorf-Richardson (JBER) along the northern perimeter of the port. The corridor, referred to as the Military Base route, provides comprehensive detour coverage and can bypass all major disruptions within the port's internal freight network. Its versatility makes it an essential emergency-use route for scenarios involving widespread access constraints. Despite its operational flexibility, the Military Base corridor is not considered viable for sustained long-term use. Constraints include military access restrictions, the extended travel distance required to reach the port, and the resulting increase in truck cycle times. As this route circumvents the standard entry via the Security Checkpoint, activation of the Military Base bypass would require temporary implementation of an alternate screening protocol. Figure 10 illustrates the Military Base detour and the associated sections of the baseline network that it replaces.

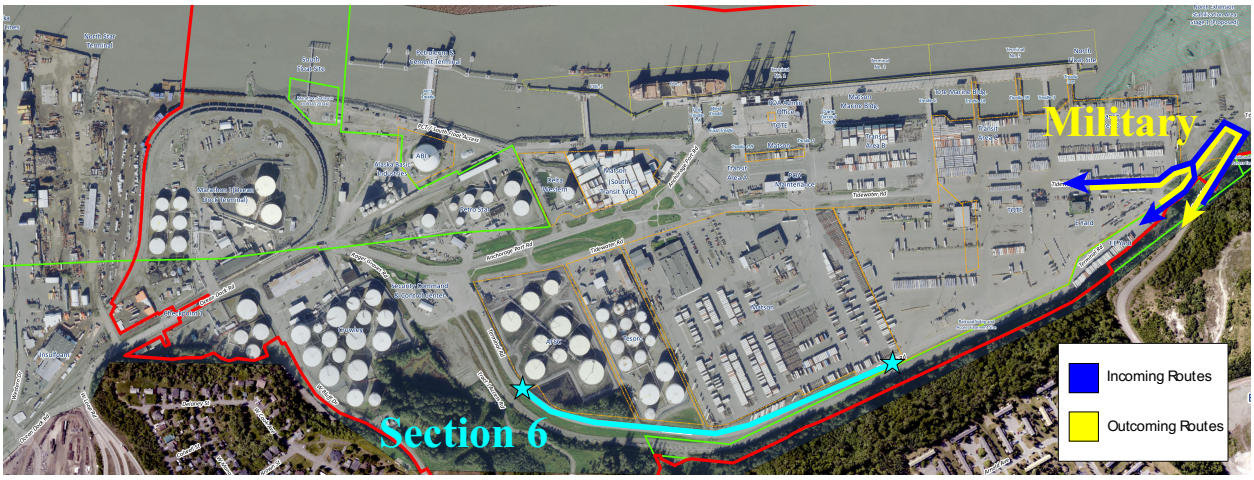


Figure 10: Proposed Military Base Route.

Alternative Route 5: Tract J Access Corridor

Tract J Access Road provides an internal route connecting to the port via Roger Graves Road near the Security Command Center. Initially intended as a strategic bypass for freight traffic, the route has since deteriorated and is currently not service-ready. Significant rehabilitation would be required before it could be deployed operationally, limiting its applicability to long-term planning scenarios. Vehicles entering through Roger Graves Road can traverse the standard internal pathways once they pass the command center. The Tract J corridor offers comprehensive bypass capabilities, covering disruptions along Ocean Dock Road as well as Anchorage Port Road up to the intersection with Terminal Road. Notably, this route circumvents all three major rail crossings along the port's primary freight corridor. Figure 11 illustrates the proposed Tract J route and the corresponding segments of the baseline freight path it is capable of bypassing.

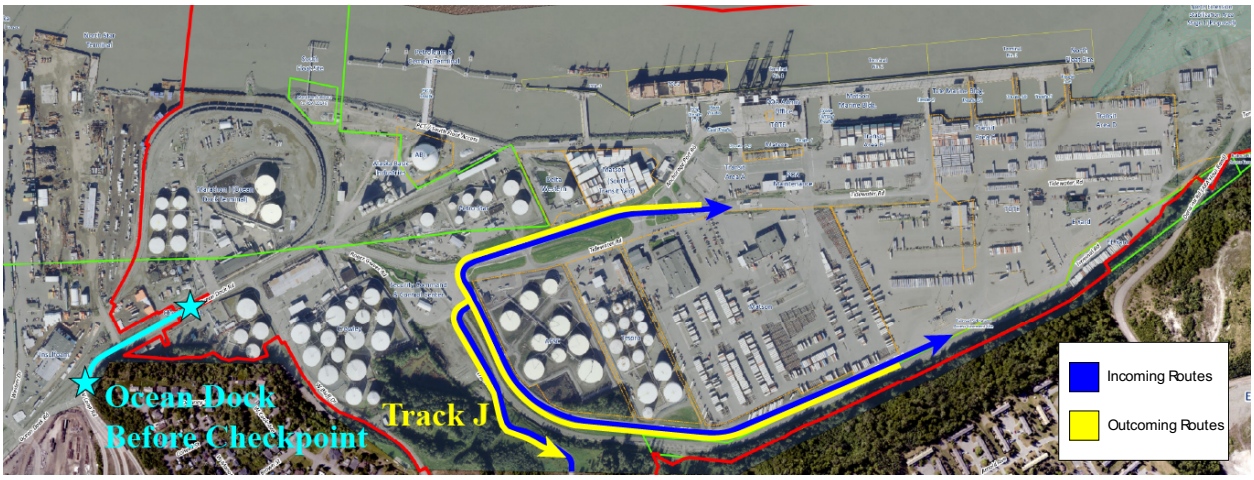


Figure 11: Tract J Route

Alternative Route 6: Transit Area A Detour

Transit Area A is a paved and currently unoccupied zone located east of the port management office. It provides a viable internal detour to bypass disruptions along Terminal Road, especially for vehicles accessing one of the major freight yards. Instead of turning onto Terminal Road from Anchorage Port Road, vehicles proceed farther along Anchorage Port Road until reaching the access to Transit Area A. They then pass through Transit Area A, connect to Tidewater Road, and continue eastward to rejoin the normal route into the freight yard. This detour avoids congestion points that may occur along Terminal Road, particularly near Section 6 of the port. Figure 12 shows the proposed Transit Area A route, along with the baseline route sections that it bypasses.

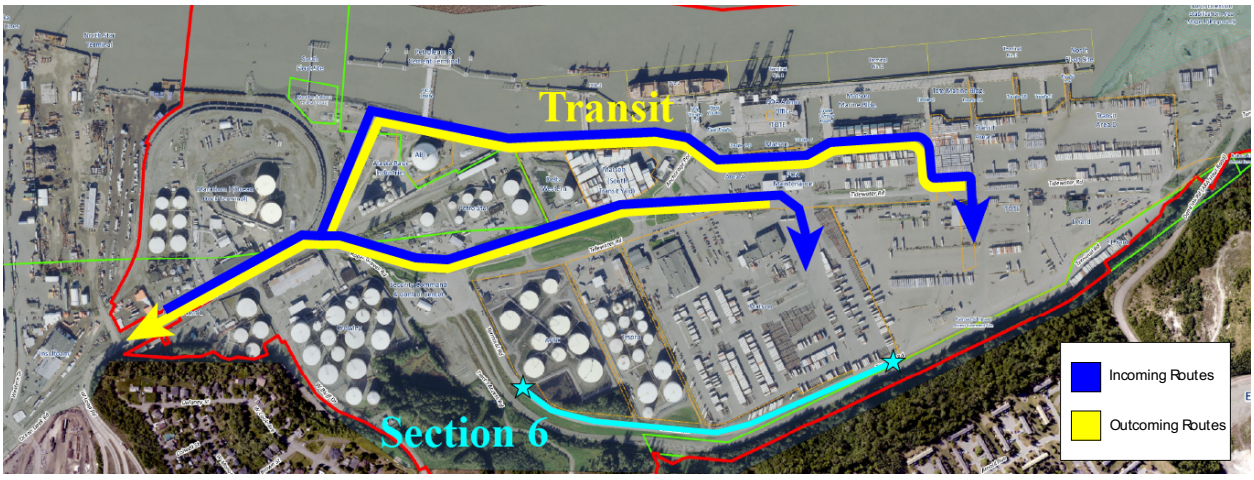


Figure 12: Proposed Transit Area A and ABI Route.

Transit Area A also supports two hybrid routing configurations involving the Marathon and ABI routes. In these cases, vehicles traveling along South Float Access Road extend their path to intersect Anchorage Port Road near Transit Area A, bypassing the original reconnection segments. These hybrid detours, designated as Marathon–Transit Area A and ABI–Transit Area A, were

proposed by port management to enhance routing flexibility under partial network disruptions. Figure 13 presents the configuration of the hybrid Marathon–Transit Area A corridor.

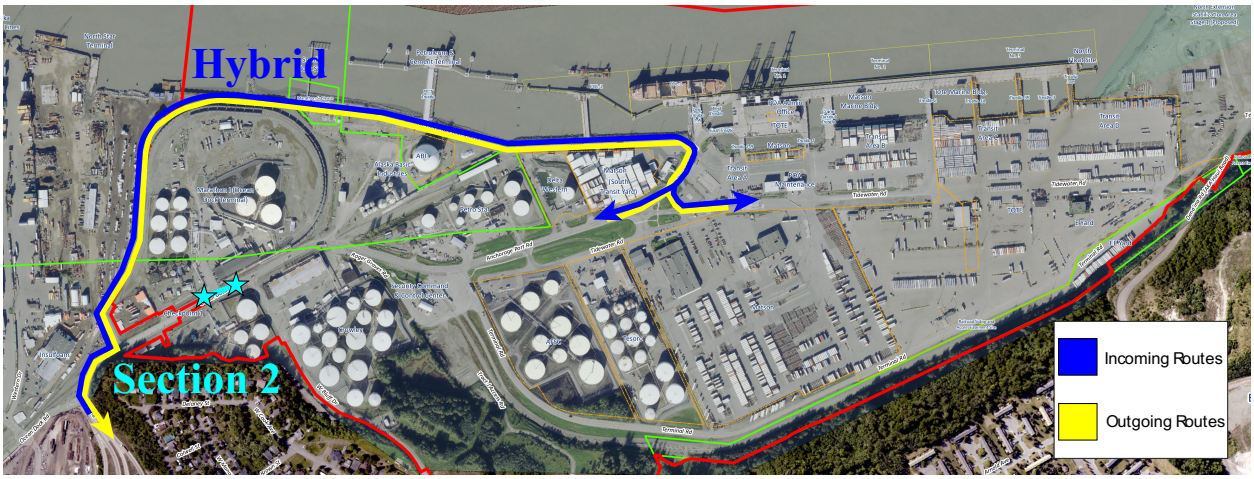


Figure 13: Marathon-Transit A Hybrid Route.

Alternative Route 7: W Bluff Drive Corridor Detour

One external detour option involves routing traffic through W Bluff Drive, which intersects Ocean Dock Road just beyond the Security Checkpoint. Although physically accessible, this corridor runs through the adjacent Government Hill residential neighborhood, where community concerns regarding noise and traffic have led to its restricted use. While not viable for sustained operations, it remains a feasible short-term bypass for localized blockages near the first rail crossing. This detour avoids the Security Checkpoint, necessitating the setup of an alternate inspection site if activated. Figure 14 illustrates the W Bluff Drive Corridor Detour and the segments it bypasses.



Figure 14: W Bluff Dr Route

***Alternative Route 8:* Roger Graves Road Corridor Detour**

A more targeted internal detour leverages Roger Graves Road to circumvent blockages along a portion of Terminal Road, including the third major rail crossing. As this road segment operates as a one-way entry route, it supports inbound truck movements only. Outbound trips would require

an alternative return corridor. Figure 15 displays the Roger Graves Road Corridor Detour and the corresponding bypassed segments.



Figure 15: Roger Graves Rd Route.

Alternative Route 9: Petro Star Corridor Detour

Another limited-scope option uses the Petro Star facility access road to detour around disruptions along a short stretch of Anchorage Port Road. This corridor requires no additional infrastructure and can be implemented rapidly during minor incidents. Figure 16 shows the Petro Star Corridor Detour and its connection with Tidewater Road.

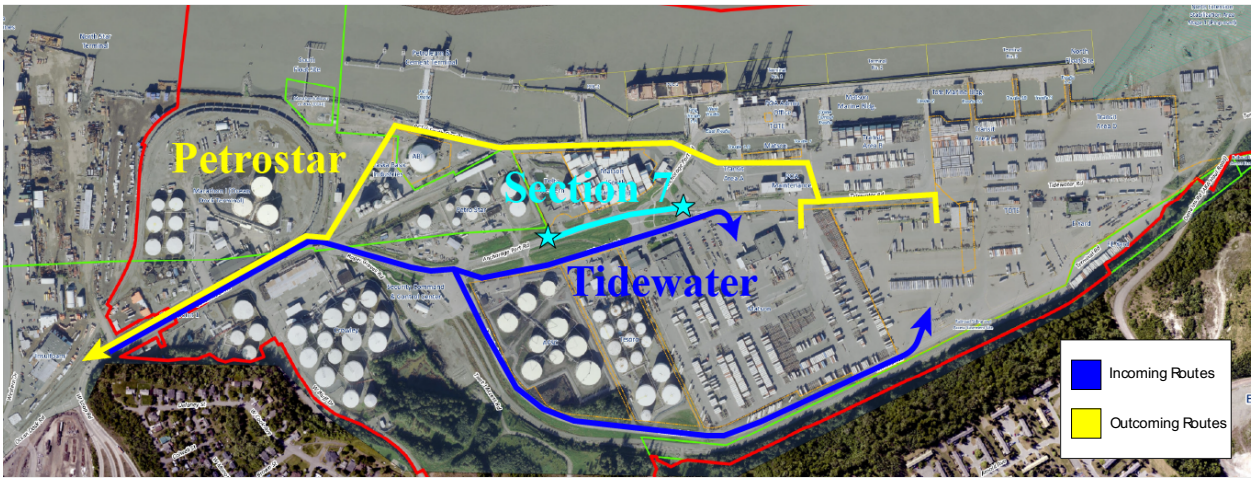


Figure 16: Proposed Tidewater Rd and Tidewater Routes.

2.4.5. Evaluation of Freight Detour Strategies and System Performance

To evaluate the operational viability of alternative routes under disruption scenarios, a series of discrete event simulation experiments is conducted using the modified baseline model. These experiments assess how well each routing alternative sustains efficient freight movement through the port network when specific segments are rendered inaccessible. Three key performance indicators are used to quantify system behavior: total cycle time, Security Checkpoint queue length, and cumulative waiting time.

- **Total cycle time** refers to the duration a vehicle requires to traverse the port from entry to exit. For the baseline and most internal detours, this time is measured from the convergence point of the two feeder roads on Ocean Dock Road to the same point upon exit. For external alternatives, such as Military Base or Tract J, the entry and exit points are redefined at the respective route's origin to maintain consistency.
- **Queue length at the Security Checkpoint** is tracked as a measure of inbound congestion. While nominal during off-peak hours, traffic surges, particularly during morning operations, can result in significant queues. Certain detour strategies may exacerbate this congestion by redirecting vehicle flow toward the checkpoint without appropriate pre-processing infrastructure.
- **Cumulative waiting time** aggregates the delays experienced by vehicles across all operational nodes, including checkpoints, freight yards, and hazardous material processing areas. This metric offers a comprehensive view of systemic delays introduced by each routing configuration and serves as a primary indicator of comparative performance.

Each candidate route is implemented by altering the routing logic in the simulation model to represent two-way freight traffic through the detour. Simulations are executed using three temporal settings to capture variability in traffic demand and operational stress:

- A full-year simulation from January 1 to December 31, 2024, reflecting annual traffic patterns.
- A low-traffic simulation for January 2024, representative of minimum volume conditions.
- A high-traffic simulation for August 2024, capturing peak seasonal congestion.

These configurations allow performance benchmarking across both typical and extreme operating conditions. Additionally, route combinations are analyzed to account for scenarios where certain corridors support only one-way freight flows. For instance, an inbound route through Tract J paired with an outbound route via Insulfoam is evaluated to test feasibility under localized blockage in Section 1. A total of 32 detour scenarios, including both individual and paired route configurations, are analyzed. Each experiment is replicated five times to ensure statistical reliability. The resulting performance measures are used to compare route-level efficiency, quantify trade-offs, and inform strategic contingency planning for maintaining uninterrupted landside operations.

2.4.6. Model Verification and Validation

Verification and validation represent critical phases in simulation modeling to ensure that the implemented logic accurately represents the operational characteristics of the real-world system. In this study, both activities were performed to establish confidence in the accuracy and reliability of the developed models.

Due to limited availability of empirical data on truck-level cycle times within the Port of Alaska's freight system, direct validation using archival data was not feasible. Instead, stakeholder-informed verification was adopted. Subject-matter experts and port personnel were consulted to obtain qualitative and quantitative estimates of key system performance indicators, including average cycle time and queue delays at critical checkpoints. These estimates served as reference points against which the simulation outputs were compared to confirm the plausibility of model behavior.

To further reinforce the integrity of the simulation logic, an independent verification approach was employed through dual-model development. A parallel model was constructed using the SimPy simulation library in Python, leveraging the same arrival patterns, processing time distributions, and routing logic as the Simio-based model. The two models were developed independently to minimize design bias and to ensure that no systematic errors were introduced during model implementation.

Outputs from both models were then compared across multiple simulation runs. Key performance indicators such as system throughput, queue length distributions, and average waiting times exhibited high consistency between the two platforms, thereby validating the model structure and embedded logic. The SimPy implementation also provided additional flexibility in customizing output reports and visualizing specific performance trends not directly supported by Simio.
Figure 17 presents a schematic comparison of the Simio and SimPy models, highlighting shared components and distinct implementation features that collectively enhance model credibility.

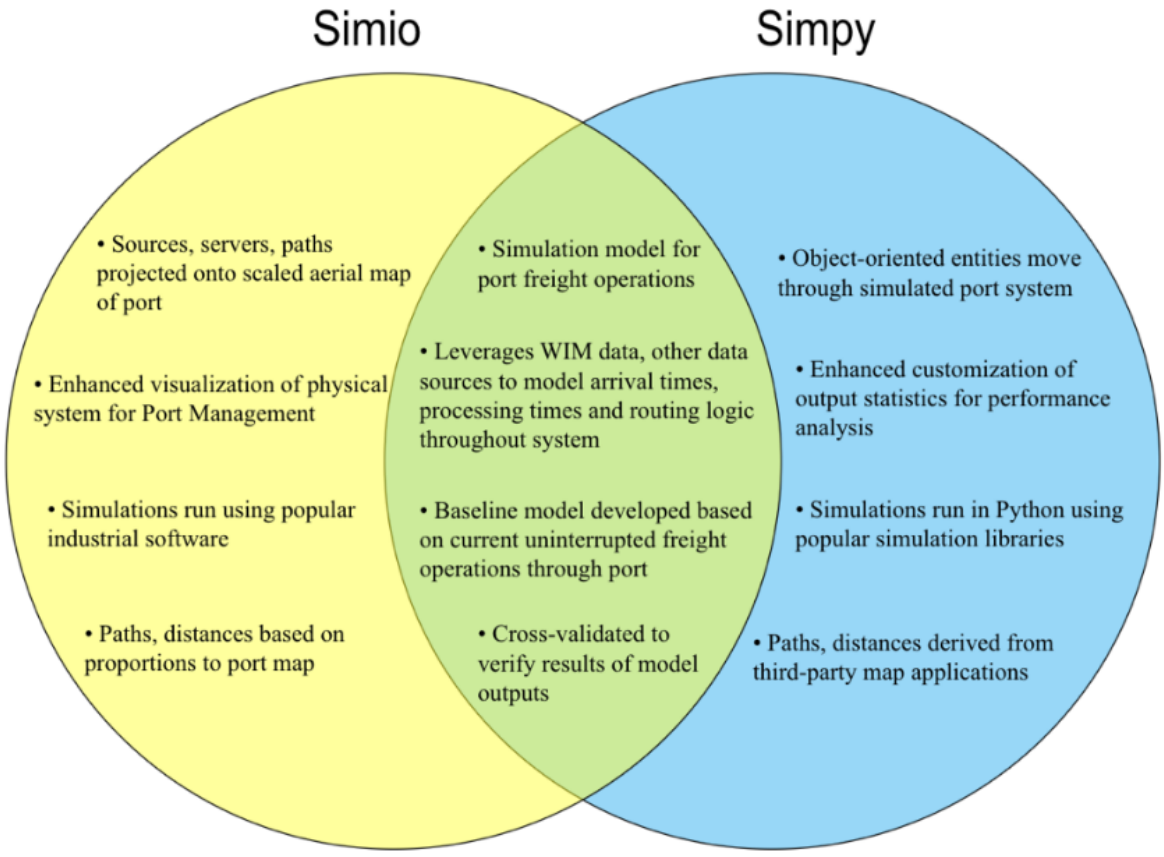


Figure 17: Comparison of Simio and Simpy Simulation Approaches for Port Freight Operations.

2.5. iFreightOps System Architecture and Functional Modules

This section outlines the architecture and core modules of iFreightOps, a cloud-based platform for managing landside freight operations at the Port of Alaska. The system integrates containerized

services for data ingestion, simulation, dashboarding, and incident management. It supports descriptive, predictive, and prescriptive analytics while enabling real-time communication through automated alerts and interactive dashboards. Key functionalities include dynamic performance monitoring, scenario-based disruption analysis, structured incident logging, and stakeholder notification tools.

2.5.1. Backend Services and Integration Strategy

The iFreightOps platform is built using a modular backend architecture where each service runs in a separate Docker container, allowing for independent deployment and updates. MongoDB serves as the centralized datastore, storing user credentials, vehicle movement records, simulation outputs, incident logs, and performance metrics. The complete system layout and interaction between components are illustrated in Figure 18.

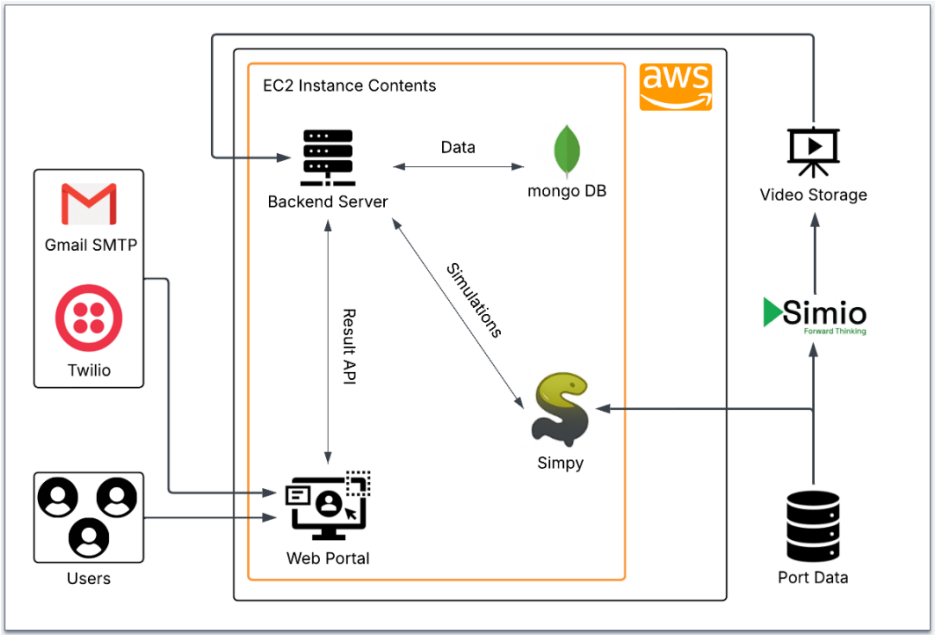


Figure 18: Architecture overview of iFreightOps

The data ingestion service collects traffic data from Alaska 511 and weather data from Visual Crossing, updating MongoDB at regular intervals. A daily cron job reconciles delayed records. Although ingestion latency averages thirty seconds, the system uses container-level autoscaling to handle data bursts exceeding five records per second.

The backend exposes RESTful APIs through a Flask service that interfaces with a React-based frontend. This combination ensures compatibility with Python-based simulation tools and supports interactive user dashboards with minimal memory overhead. Benchmarking against alternative frameworks confirmed that this stack best balances responsiveness and scalability.

Simulation services include two components. SimPy is used to compute hourly metrics such as arrival rates, queue lengths, and cycle times. Simio supports scenario playback by generating video-based representations of port activity under disruption. Both tools read input from MongoDB, execute simulations, and update the datastore to ensure the dashboard reflects current

conditions. Validation showed that the average cycle time estimates remained within ten percent of observed values when sensor latency was below five minutes.

A notification engine continuously monitors simulation outputs and triggers alerts via Twilio (SMS) and Gmail SMTP (email) when key metrics exceed the 95th percentile of historical baselines. This functionality enables prescriptive responses to emerging bottlenecks.
Figure 19 shows the overall data flow from user authentication through simulation execution to alert dissemination. The diagram illustrates descriptive analytics in the dashboard, predictive analytics in the forecast engine, and prescriptive analytics in the scenario analysis engine, connecting this subsection directly to the three analytic categories outlined in the introduction.

System scalability is supported through an Application Load Balancer, container autoscaling, and sharded MongoDB collections. Stress testing confirmed that performance remains stable with up to two hundred concurrent dashboard sessions, with throughput remaining linear until CPU utilization reaches seventy percent. Migration of long-running simulations to AWS Batch is planned to further enhance scalability and remove single-node constraints.

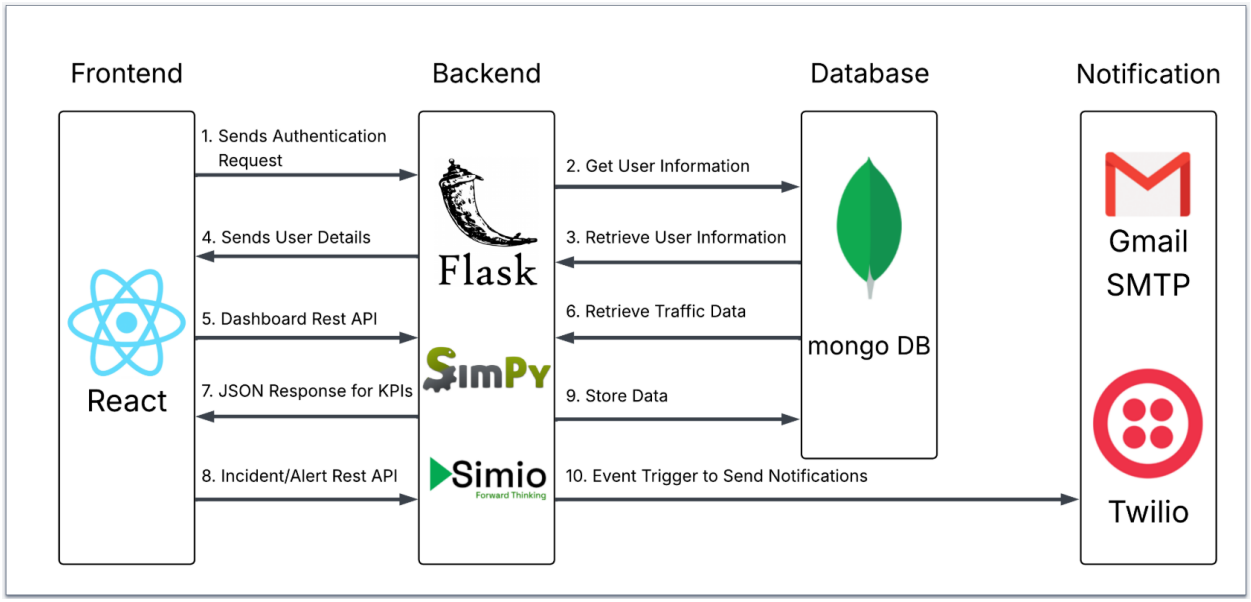


Figure 19: High-level flow of iFreightOps.

2.5.2. Scenario Analysis Module

This module integrates data-driven simulation with an interactive interface that enables stakeholders to define disruption scenarios and evaluate corresponding mitigation strategies. It supports both operational decision-making and long-term infrastructure planning by addressing two primary goals: (i) to replicate the effects of short-term and long-term blockages on port-access corridors and quantify their impact on key performance indicators such as waiting time and total cycle time across all feasible detours; and (ii) to rank response strategies that minimize immediate disruption while identifying corridors with persistent vulnerabilities that warrant long-term capital improvements.

The primary data source for this module is the monthly archive of weigh-in-motion (WIM) records from the Alaska 511 website. Upon upload, an automated Extract–Transfer–Load (ETL) pipeline cleanses the data by removing corrupt rows, resolving duplicate timestamps, and aggregating weight classifications into truck and light vehicle categories. Missing data points are imputed using historical averages for the same month, day of the week, and hour.

A discrete-event simulation engine models landside traffic under three operational regimes: (1) baseline (no closure), (2) no-reaction (closure with habitual routing), and (3) detour (closure with dynamic diversion). Hourly vehicle arrivals are sampled from the cleaned WIM tables, follow a Poisson distribution with the historical hourly mean, and are evenly timestamped within each hour. Vehicles compete for gate access, experience stochastic service durations, traverse seasonal-adjusted road segments, and, in the case of trucks, incur additional delays associated with terminal loading. For each run, the simulator records gate waiting time, travel time, terminal dwell, and total cycle time.

Disruption segments and their associated detours were identified through structured interviews with terminal operators, the port manager, and local carriers. Users may manually configure the closure location, start time, and duration. For each scenario, the simulation outputs both raw performance indicators, maximum and average waiting and cycle times, and summary decision metrics: percentage reduction in average cycle time, 95th-percentile queue length, and estimated economic cost of delay. A recommended response strategy is flagged when at least two of the three decision metrics show improvement over the baseline.

Figure 20 illustrates the interactive interface. The left panel allows users to specify disruption characteristics and optionally upload new WIM files. A single click initiates the simulation. The center panel displays comparative box plots of key metrics across the three regimes, along with a summary table of mean and maximum values. Below this, a risk-assessment matrix integrates route diversity, traffic volume, and detour performance to generate a severity score. The right-hand panel shows a simulation video for the selected disruption and its corresponding detour route, alongside a map view that marks the blocked section and highlights the activated detour.

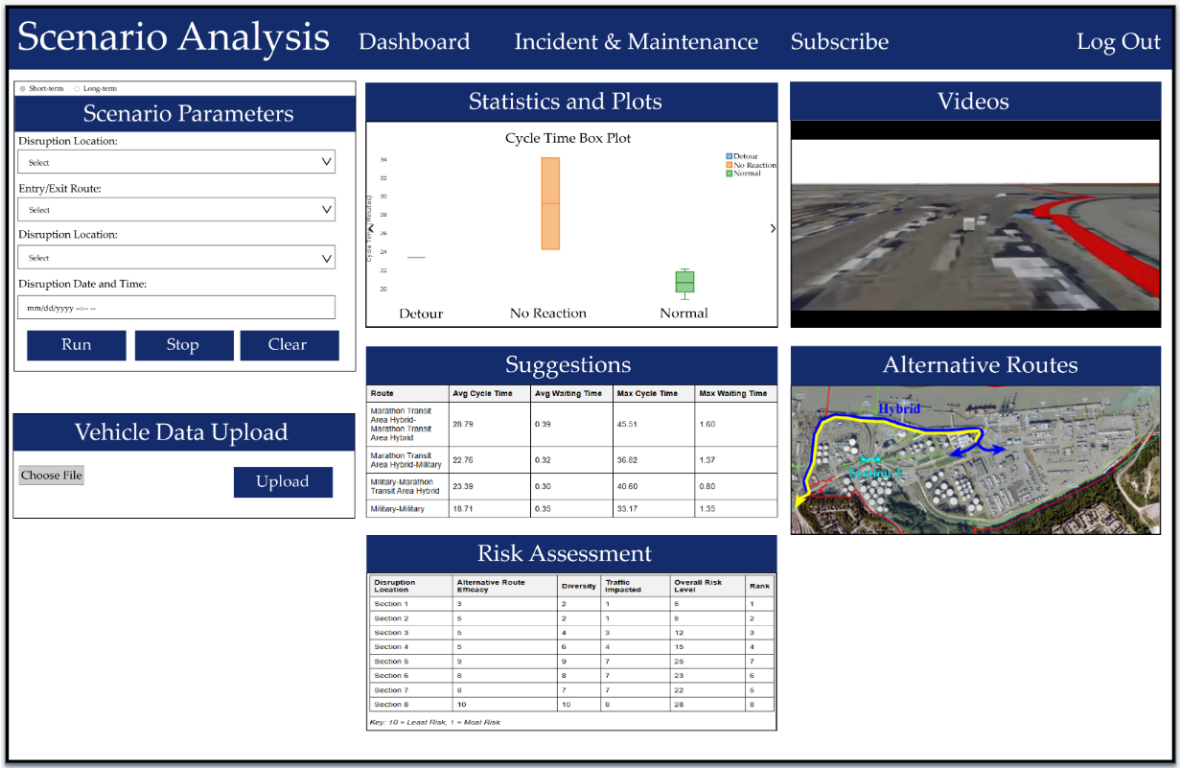


Figure 20: Interactive user interface of the Scenario Analysis module.

2.5.3. Dynamic Traffic Dashboard Module with Predictive Capabilities

The Dynamic Traffic Dashboard provides short-horizon forecasts of key port performance indicators, offering stakeholders a forward-looking view of expected operational conditions rather than real-time monitoring. It supports day-level planning decisions by combining historical trends with simulated traffic projections. The predictive engine underlying the dashboard uses archived weigh-in-motion (WIM) records. At the end of each day, it applies a Monte Carlo resampling method that selects historical records corresponding to the same calendar month and day of the week as the target date. These records are re-weighted using recent demand growth trends to generate realistic traffic forecasts. The resulting distributional estimates populate each dashboard widget.

Figure 21 illustrates the layout of the traffic dashboard. The three panels on the left display forecasted hourly profiles for cycle time, vehicle arrivals, and waiting time, along with 95% confidence intervals. A filter bar allows users to switch between estimates for trucks, cars, or combined traffic. At the center, an interactive map displays port access corridors. Selecting a marker updates all graphs to reflect location-specific forecasts, while double-clicking restores the full network view. This spatial drill-down capability helps yard supervisors assess relative corridor-level risks before assigning resources. The right-hand panel supports longer-term planning through pattern recognition. A month–hour heat map visualizes seasonal fluctuations in throughput, while a weekday–hour matrix identifies recurring peak periods that guide roster and shift scheduling. These patterns are refreshed after each nightly forecast run. Below the map, the table *Expected Vehicles in Each Section* displays the forecasted mean vehicle count for the current day, along with the associated 95% confidence range.

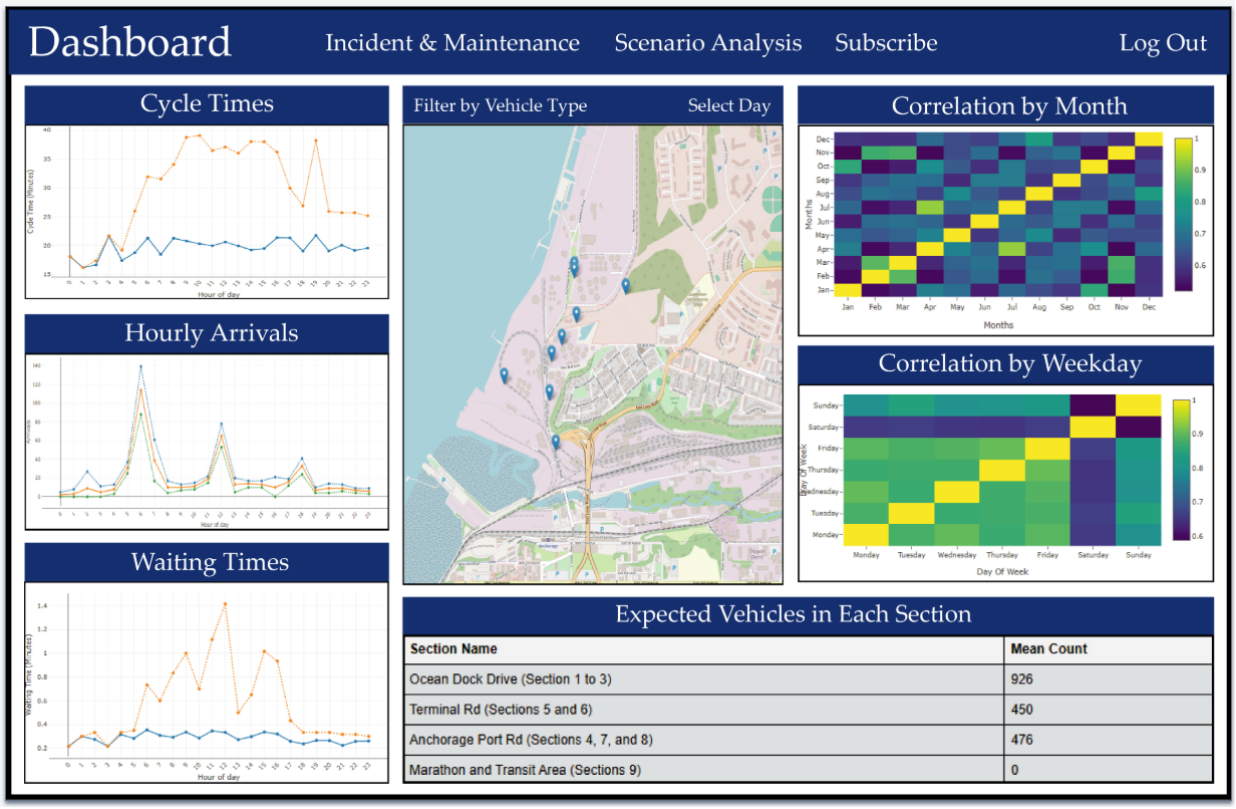


Figure 21: Interactive user interface of the Dynamic Traffic Dashboard.

2.5.4. Incident Management and Communication Module

This module provides a structured interface for registering, monitoring, and broadcasting disruptions, including minor accidents, infrastructure failures, and scheduled maintenance events (Figure 22). The interface enables port operators to document disruptions via a form that captures the incident name, category, geocoordinates, start and expected end time, root cause, and recommended detour. Once an incident is submitted, it is visualized on the central map as a color-coded marker, with the color indicating severity. Simultaneously, the right-hand panel displays a list of all active incidents, accompanied by facet filters for rapid querying based on type, location, or status. A clearance horizon gauge, positioned below the list, provides an estimate of resolution time derived from historical incident data. These predictions can be manually adjusted by port management. To facilitate external coordination, the system supports enrollment of shipping carriers, trucking companies, and public agencies through a subscription interface. Notifications are dispatched via email and SMS, ensuring timely updates across communication channels.

While manual entry offers flexibility, it may become a bottleneck during high-traffic periods. To address this, a RESTful connector to the port's dispatch system is planned for the next release, enabling automatic ingestion of verified incident data. The module is built on a microservice architecture, using Docker Compose for local testing and Amazon ECS for production deployment. Auto-scaling mechanisms are configured to duplicate front-end instances and provision read-only MongoDB replicas when CPU or I/O usage exceeds predefined thresholds.

Planned enhancements include: (i) deployment of serverless simulation containers to estimate network-wide impacts in near real time, and (ii) integration of an anomaly detection pipeline to identify and isolate sensor irregularities before they compromise analytics integrity.

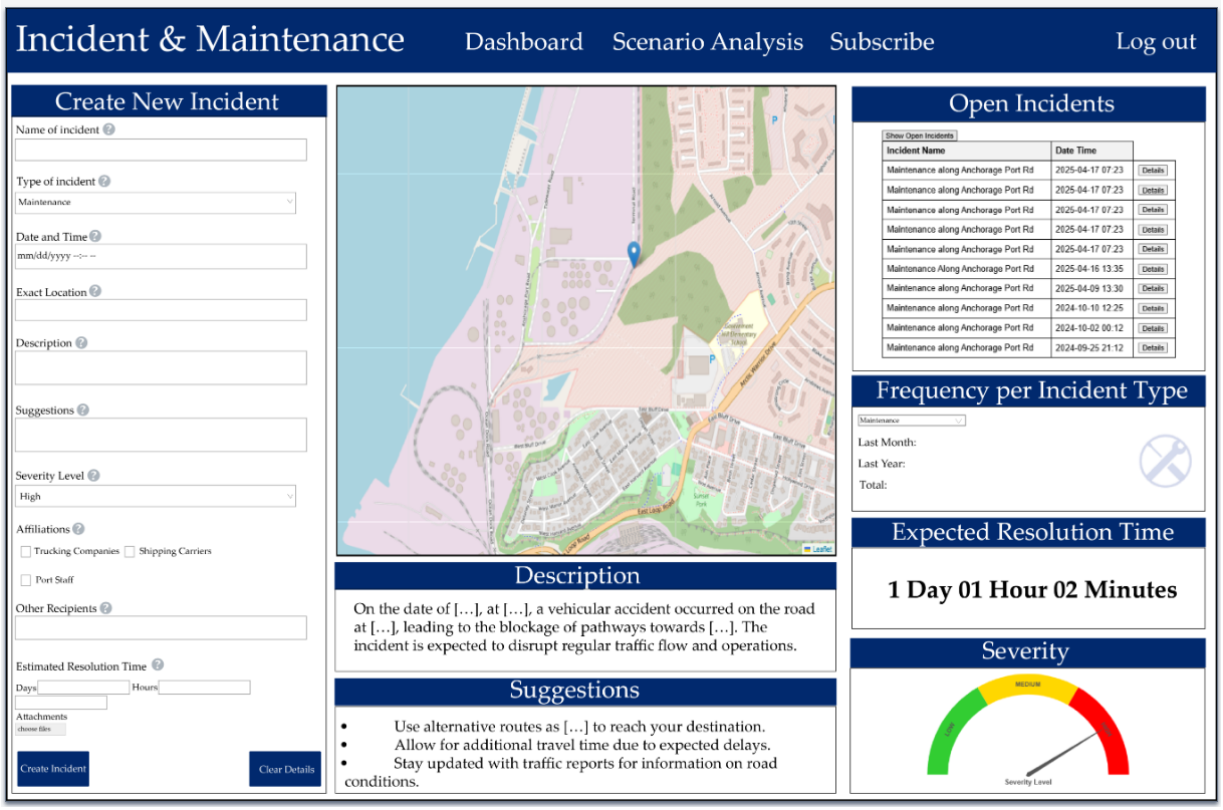


Figure 22: Interactive user interface of the Incident Management module.

2.6. Results and Analysis

2.6.1. Evaluation of Routing Alternatives and Disruption Impacts

The evaluation of baseline and alternative truck routing configurations was conducted using a Simio-based discrete-event simulation model. Under current operating conditions, the average freight truck cycle time across a full year is approximately 24.5 minutes, consistent with stakeholder estimates and independently validated using a SimPy model. Peak observed values include a total waiting time of 6.4 minutes and a maximum queue length of 27 vehicles. Because congestion is infrequent, the average queue length over the simulation horizon is just 0.22 vehicles, and the mean total waiting time is approximately 20 seconds. These results confirm that existing port operations adequately meet current freight traffic demand, a conclusion supported by port management and key stakeholders.

To assess the resilience of the freight system under disruption, three simulation scenarios were run for each routing configuration: (i) a full-year baseline, (ii) a low-traffic month, and (iii) a high-traffic month. Table 1 summarizes the average cycle time, total waiting time, and checkpoint queue length for each routing configuration. Despite cycle time increases ranging from 0.3 to 4.6 minutes depending on the detour route, the system maintains throughput efficiency and avoids excessive queuing. Notably, several alternatives (e.g., Marathon, ABI, W Bluff Dr) demonstrate strong performance across all three indicators, suggesting they are viable fallback options during access disruptions. This operational stability can be attributed to three factors: (i) the location of the security checkpoint early in the freight process, (ii) consistent arrival trends across simulations, and (iii) uniform internal routing logic that preserves downstream flow. These features prevent

congestion from propagating through critical nodes, such as the HazMat Lane or maintenance facilities. As a result, the port system avoids gridlock, even under rerouting conditions.

Table 1: Performance metrics for baseline and alternative routes under disruption scenarios.

Route	Avg Cycle Time (min)	Avg Total Waiting Time (sec)	Avg Checkpoint Queue Length
Baseline	24.5	18.72	0.216
Alternative Route 1	28.2	20.52	0.228
Alternative Route 2	29.1	18.66	0.212
Alternative Route 3	27.5	18.78	0.217
Alternative Route 4	25.7	18.72	0.216
Alternative Route 5	25.3	18.84	0.217
Alternative Route 6	27.6	18.6	0.219
Alternative Route 7	24.8	18.72	0.216
Alternative Route 8	25.3	18.78	0.217
Alternative Route 9	25.8	18.72	0.218
Hybrid Alternative Route 2&3	27.1	18.72	0.216
Hybrid Alternative Route 2&6	28.7	18.66	0.215

In summary, the simulation results demonstrate that carefully selected alternative routes can preserve operational continuity and performance despite road access disruptions. The alternatives evaluated here not only minimize delays but also prevent cascading congestion, offering port operators a set of flexible and effective contingency options.

In addition to performance metrics, each alternative route was evaluated based on its practical feasibility for implementation. Two key dimensions were considered: (i) the estimated investment cost required to bring each route into operational service, and (ii) the level of stakeholder conflict likely to arise from rerouting freight traffic through that corridor. These factors provide port decision-makers with insights into the trade-offs between operational benefit and implementation burden.

Implementation cost was categorized into three tiers: no cost (readily usable with existing infrastructure), moderate cost (less than $10,000), and high cost (greater than $10,000). Potential stakeholder conflict was assessed based on anticipated resistance from internal or external entities, including port tenants (internal), surrounding residential neighborhoods, and the military installation at JBER (external). Conflict levels were classified as low, moderate, or high. Table 2 summarizes the classification of each alternative route across both dimensions, along with the number of disruption-prone sections each route can bypass.

Table 2: Alternative Route Cost and Potential Comparison.

Alternative Route	Estimated Implementation Cost	Potential Conflict	Number of Sections Bypassed
Baseline	< $10,000	High	1
Alternative Route 1	< $10,000	Moderate	4
Alternative Route 2	< $10,000	Moderate	2
Alternative Route 3	$0	High	9
Alternative Route 4	$0	High	5
Alternative Route 5	> $10,000	Low	2
Alternative Route 6	$0	High	2
Alternative Route 7	$0	Low	1
Alternative Route 8	$0	Moderate	1
Alternative Route 9	$0	Low	1
Hybrid Alternative Route 2&3	< $10,000	Moderate	6
Hybrid Alternative Route 2&6	< $10,000	Moderate	8

To assess the functional versatility of each detour, routes were further analyzed based on their coverage, defined as the number of disrupted sections they are capable of bypassing. This metric reflects the adaptability of each alternative to a range of possible blockage locations. As shown in Table 3, multi-segment routes such as the Military Base, ABI–Transit Area Hybrid, and Marathon–Transit Area Hybrid provide coverage across the highest number of disruption-prone segments.

Table 3: Sections Bypassed by each Alternative Route.

Alternative Route	Baseline Sections Bypassed	Number of Sections Bypassed
Baseline	1	1
Alternative Route 1	2, 3, 4, 5	4
Alternative Route 2	4, 5	2
Alternative Route 3	1, 2, 3, 4, 5, 6, 7, 8, 9	9
Alternative Route 4	1, 2, 3, 4, 5	5
Alternative Route 5	6, 7	2
Alternative Route 6	1, 2	2
Alternative Route 7	6	1
Alternative Route 8	8	1
Alternative Route 9	9	1
Hybrid Alternative Route 2&3	4, 5, 6, 7, 8, 9	6
Hybrid Alternative Route 2&6	2, 3, 4, 5, 6, 7, 8, 9	8

Finally, a disruption risk profile was developed for the port's internal network by evaluating each segment based on (i) the number of alternative detour routes available, and (ii) the volume of freight traffic that relies on that segment under baseline conditions. Segments with few bypass options and high usage levels represent operational bottlenecks. The usage factor was defined as the proportion of total port traffic that must traverse the segment in question. For instance, Sections 1 and 2 carry 100 percent of port-bound freight traffic and have limited detour redundancy, placing

them in the highest-risk category. Section 6, on the other hand, has a usage factor of 0.37, indicating that approximately 37% of port-bound vehicles traverse this segment under baseline conditions. Table 4 details the number of available alternatives and the usage factor for each section.

Table 4: Number of Available Alternatives and Usage Factor of each Section.

Disruption Section	Number of Available Alternative Routes	Usage Factor
1	4	1.00
2	5	1.00
3	4	0.97
4	6	0.97
5	6	0.88
6	5	0.37
7	4	0.37
8	6	0.51
9	4	0.51

Overall, the disruption analysis highlights the importance of both operational performance and implementation feasibility in selecting effective detour strategies. While all alternative routes maintain system stability and prevent downstream congestion, their suitability varies based on coverage breadth, infrastructure readiness, and stakeholder alignment. High-performing alternatives such as the Military Base and hybrid routes demonstrate strong versatility in bypassing multiple segments but may involve greater coordination challenges. Conversely, lower-cost, low-conflict routes offer immediate usability but limited disruption coverage. These findings provide a structured basis for prioritizing route investments and developing a tiered response framework that balances resilience, feasibility, and stakeholder impact.

2.6.2. Analytical Results for Traffic Patterns and Incident Management

This section illustrates how the analytical modules within iFreightOps support data-driven responses to operational challenges at the port. While the platform is not designed to serve as a standalone decision-making tool, it provides critical insights that can inform and complement managerial judgment. In particular, it enables quantitative evaluation of the operational impact of infrastructure changes such as gate reopening or detour route activations, offering a valuable decision-support layer in otherwise multi-factorial and stakeholder-sensitive planning contexts.

Descriptive Analytics

Using historical port traffic data continuously ingested by iFreightOps since 2021, the platform generates temporal distribution summaries across monthly, weekly, and hourly scales. As shown in Figure 23, these distributions exhibit consistent seasonal and daily patterns. Port activity increases sharply from May through September, with August marking the peak of inbound traffic. Weekly patterns reveal that Tuesdays consistently register the highest volumes, while weekends, particularly Saturdays, remain comparatively light. Hourly analysis shows clear morning peaks between 8:00 and 10:00 AM, followed by reduced activity from 6:00 PM onward.

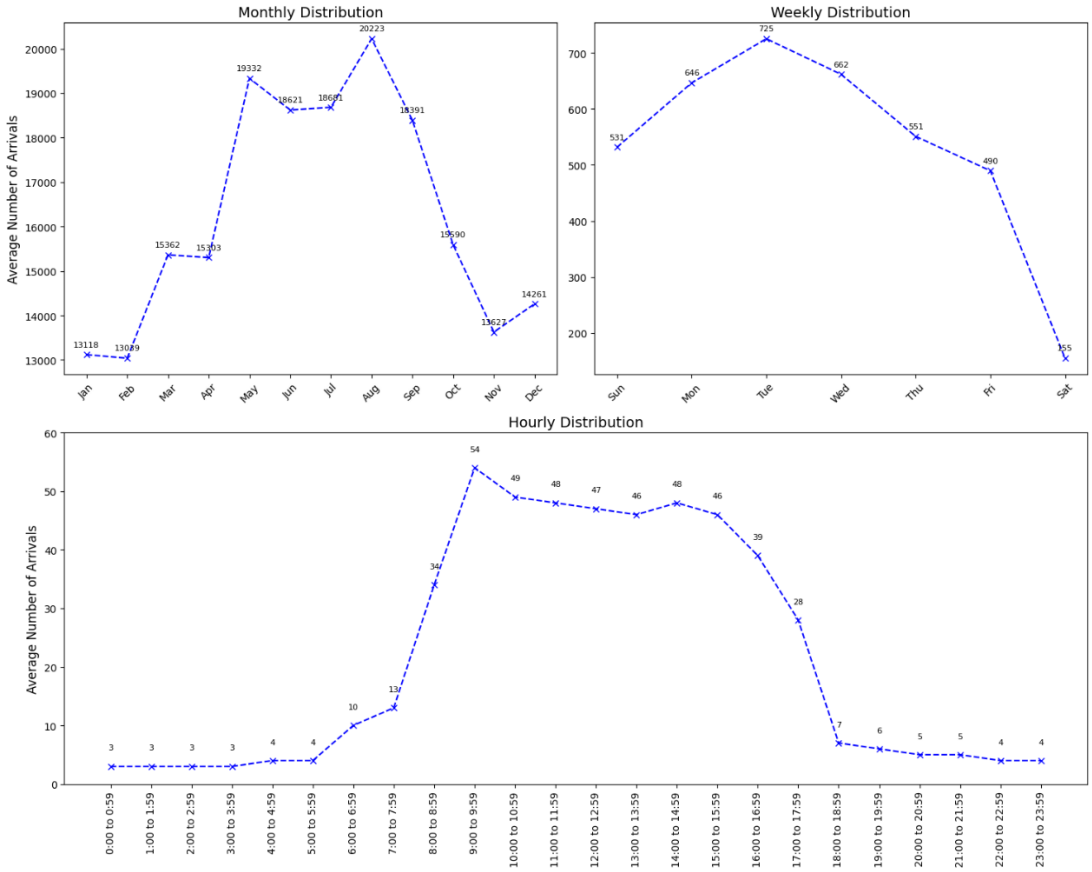


Figure 23: Observed monthly, weekly, and daily traffic patterns at the port based on iFreightOps data.

Correlation analysis across weekdays, visualized in Figure 24, reveals strong inter-day dependencies. For example, high inbound volumes on Monday and Tuesday are often indicative of elevated mid-week activity. These insights provide a foundation for workload balancing and shift planning by terminal operators.

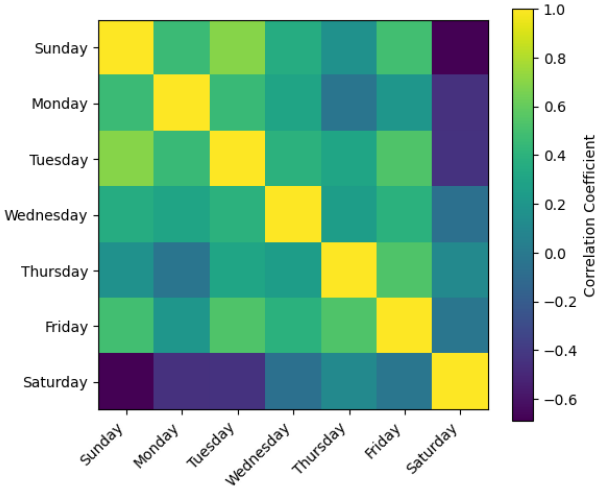


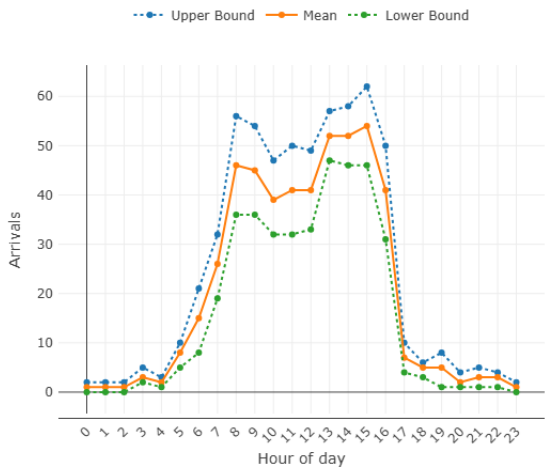
Figure 24: Heatmap showing the correlation of port traffic volumes between different weekdays, based on iFreightOps data

These temporal trends also guide targeted interventions. For example, Tract J, located near a residential area, can be managed more effectively by limiting usage during peak morning periods. Similarly, pronounced weekday congestion patterns can inform decisions on gate schedules or access control. Notably, the introduction of iFreightOps enabled structured logging and visualization of incident reports, which were previously undocumented. Although the dataset remains limited, it now tracks six categories: Emergency Response, Maintenance, Traffic Congestion, Equipment Failure, Route Change, and Accidents.

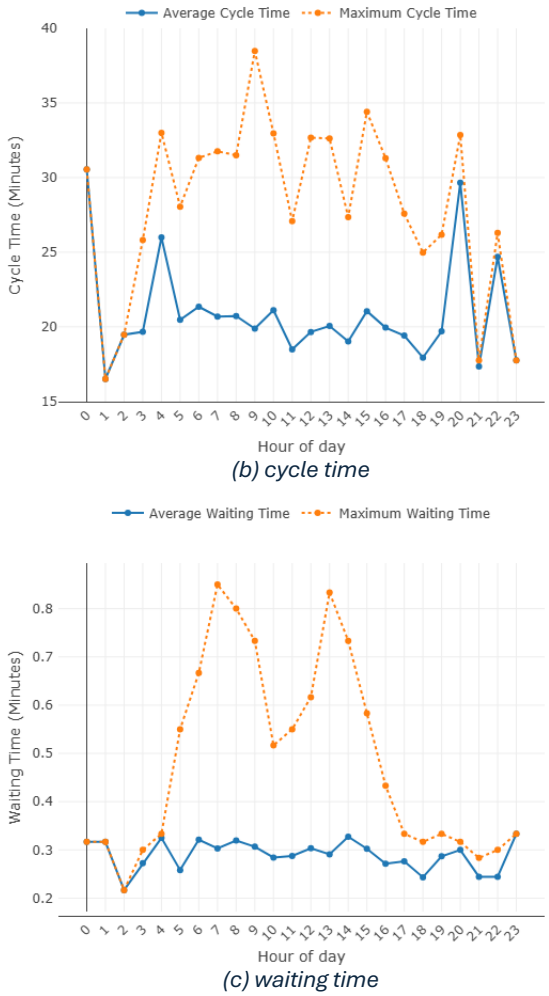
Predictive Analytics

The predictive engine within iFreightOps generates short-term forecasts for traffic volumes and key performance indicators (KPIs) under both normal and disrupted conditions. Using historical data, vehicle arrival rates segmented by hour, day, and month are modeled as Poisson processes, with arrival rate, λ, computed from past observations. Within each simulated hour, arrival times are uniformly distributed. Multiple simulation replications are conducted to estimate forecast confidence intervals. Figure 25 shows selected forecast visualizations presented on the platform dashboard. These include 90% confidence bands for daily arrivals segmented by vehicle type (cars, trucks, combined), as well as predictive distributions for average and maximum waiting time and cycle time. Forecasts are generated each night and available for the current day and the subsequent six-day horizon.

To support disruption management, the forecasting module is integrated with the simulation engine to evaluate incident impacts by corridor and duration. Incidents are classified as short-term (≤1 day) or long-term (>1 day), with the former typically involving snow accumulation or equipment failures, and the latter covering scheduled repairs and infrastructure projects.



(a) truck arrivals



(b) cycle time

(c) waiting time

Figure 25: Forecast indicators generated by iFreightOps.

Prescriptive Analytics

The prescriptive module builds on descriptive trends and predictive outputs to generate actionable recommendations. It uses a structured risk-scoring framework to prioritize responses to both short-term disruptions and long-term infrastructure investments.

- **Short-Term Disruption Scoring:** Each corridor segment is evaluated using a three-factor scoring model:
    - **Alternative Route Efficacy (ARE):** Captures the relative degradation in average cycle time and waiting time under detour conditions compared to baseline.
    - **Route Diversity (RD):** Measures the number of viable detour options available for the segment.
    - **Traffic Impacted (TI):** Reflects the percentage of daily truck traffic affected by a blockage at the location.

Each score is normalized on a 1–10 scale (10 = least risk). The aggregate score, calculated using a simple additive index, supports prioritization for operational response planning. Table 5 presents the short-term risk scores across all major corridor segments.

Table 5: Risk-assessment matrix for short-term corridor disruptions (Key: 10 = Least Risk, 1 = Most Risk)

Disruption Location	Alternative Route Efficacy	Route Diversity	Traffic Impacted	Overall Risk Score	Rank
Section 1	3	2	1	6	1
Section 2	5	2	1	8	2
Section 3	5	4	3	12	3
Section 4	5	6	4	15	4
Section 5	9	9	7	25	8
Section 6	8	8	7	23	6
Section 7	8	7	7	22	5
Section 8	10	10	8	28	9
Section 9	8	10	5	23	6

- **Long-Term Infrastructure Scoring:** For infrastructure planning, a similar three-factor framework is applied:
    - **Ease of Implementation (EI):** A qualitative composite metric that considers cost, permitting, environmental constraints, and project timeline.
    - **Relative Performance (RP):** Simulated performance improvement relative to the baseline using KPIs such as mean/max cycle and waiting times.
    - **Route Diversity (RD):** The additional network redundancy gained, quantified via edge betweenness centrality improvement.

As shown in Table 6, each proposed infrastructure project is scored on the same 1–10 scale, facilitating comparative evaluation and investment prioritization.

Table 6: Risk-assessment matrix for long-term corridor disruptions (Key: 10 = Least Risk, 1 = Most Risk)

Criteria	Tract J	Marathon	Transit Area
Ease of Implementation	1	7	8
Relative Performance	3	4	8
Route Diversity	7	7	4
Overall Efficacy Score	11	18	20
Rank	8	4	2

3. INTERPRETATION, APPRAISAL, AND APPLICATIONS

3.1. Alternative Routing Recommendations

Based on the obtained results from the simulation modeling and comprehensive analysis of potential alternative routes, the following routing strategies are recommended to improve the resilience of the port's internal freight network.

For short-term disruption response, the hybrid configurations Marathon (inbound) – Transit Area A (outbound) and ABI (inbound) – Transit Area A (outbound) should be maintained in operational condition for two-way freight service. These hybrid routes demonstrate the highest bypass coverage, 8 and 6 disruption-prone sections, respectively, at a relatively low implementation cost

(under $10,000). Although they result in increased average cycle times (17.1% for the Marathon hybrid and 10.1% for the ABI hybrid), no other combination of alternatives provides comparable detour flexibility. Together, these two configurations enable operational continuity for 8 out of 9 potential blockage sections, particularly during short-term disruptions caused by traffic accidents or weather-related events. For temporary access loss at the port entrance (Section 1, Ocean Dock Road), the W Bluff Dr route is recommended for short-duration diversions. While this route passes through the Government Hill neighborhood, stakeholder conflict is limited when usage is infrequent and time-bound.

For long-term scenarios, the same two hybrid configurations remain the most versatile options, contingent on effective coordination with internal stakeholders occupying the ABI and Marathon lots. These routes enable access to a majority of the port's internal road network in the event of prolonged disruptions. For long-term blockages at Section 1, the Insulfoam detour offers the most feasible alternative, assuming it remains structurally usable. Other options, such as Tract J, Military Base, or W Bluff Dr, involve significant political, logistical, or financial barriers. The importance of Section 1 is further underscored by the presence of a critical at-grade railroad crossing on Ocean Dock Road. With planned rail realignment projects underway, prolonged disruptions related to construction or closure of this crossing could severely impact port operations unless a viable bypass is secured in advance.

Beyond specific routing strategies, the overarching recommendation is clear: ensuring the availability of at least one functional bypass for each segment of the baseline network is critical to operational continuity. Implementation costs or stakeholder conflicts must be balanced against the far greater risk of complete system shutdown. Any emergency response plan adopted by port management must explicitly incorporate alternative routes capable of circumventing all nine potential disruption segments to maintain uninterrupted freight movement and safeguard the broader Alaskan supply chain.

3.2. Practical Implications

The iFreightOps platform supports port management in addressing several pressing operational challenges, including single-gate constraints, railway disruptions, infrastructure planning, and route-level congestion mitigation.

To alleviate congestion related to the single-gate constraint, iFreightOps leverages real-time monitoring and proactive scheduling capabilities. The Dashboard module provides forecasted key performance indicators (KPIs) based on historical data, such as hourly vehicle arrivals, cycle times, and waiting times. Using this information, port managers can shift truck appointments from peak periods (e.g., 08:00–10:00) to off-peak times (e.g., after 18:00) to reduce queuing. Additionally, the Scenario Analysis module allows simulation of potential capacity expansions, such as adding extra gates, helping quantify improvements like shorter cycle times and reduced waiting durations. These insights directly support the port's ongoing modernization initiatives and improve resilience during severe weather disruptions that affect the primary gate.

Railway-corridor disruptions, typically caused by temporary rail-road crossing blockages, are addressed through simulation modeling and communication tools. The Scenario Analysis module assesses the performance of detour routes, such as the Military-Marathon hybrid route, by

generating detailed metrics. Simultaneously, the Incident Management module sends timely SMS and email alerts to enable immediate rerouting during disruptions. The system's historical logging capabilities also facilitate post-incident analysis and continuous improvement.

For infrastructure planning, iFreightOps enhances decision-making regarding semi-completed roads like Tract J and future routes such as Marathon Road. Predictive simulations generated by the Scenario Analysis module estimate future cycle times and highlight anticipated implementation challenges. These forecasts help guide long-term infrastructure investments. Furthermore, traffic volume projections from the Dashboard module support the allocation of resources during construction phases to minimize disruption.

Targeted scenario evaluations also help optimize the use of alternative routes, such as those involving the Transit Area, during times when Container Yard 1 is blocked or vessel activity is low. Simulation results reveal efficiency gains when these alternative routes are used strategically. Combined with real-time alerts from the Incident Management module, the system allows port schedulers to proactively manage vehicle flows and maintain operational performance during unexpected disruptions.

3.3. Managerial Implications

iFreightOps enhances decision-making across six managerial domains: truck scheduling, resource allocation, infrastructure investment, alternative routing, stakeholder communication, and incident diagnosis.

- Truck scheduling benefits from detailed traffic forecasts that guide appointment timing to reduce congestion during peak periods.
- Resource allocation is improved through dashboard visualizations that highlight congestion trends and spatial demand patterns, allowing dynamic reassignment of personnel and assets.
- Infrastructure expansion planning is supported through scenario-based performance comparisons and risk assessments that identify high-impact investments, such as new gate locations or route upgrades.
- Alternative routing decisions are informed by comparative evaluations of cycle time, delay reduction, and coverage provided by different detour options under both short- and long-term conditions.
- Stakeholder communication is enhanced through automated SMS and email notifications, which support coordinated responses during unplanned disruptions and minimize information asymmetries with carriers.
- Root-cause analysis is enabled by incident tracking tools, allowing detection of recurring bottlenecks (e.g., snow-related delays or rail conflicts) and the formulation of preventive or corrective policies.

In summary, the managerial implications of iFreightOps extend beyond reactive incident response, enabling proactive planning, operational optimization, and strategic infrastructure investments that collectively strengthen the port's resilience and performance under both routine and disrupted conditions.

4. CONCLUSIONS AND SUGGESTED RESEARCH

This study highlights the potential of integrated analytics platforms to enhance landside freight operations in complex port environments. Centered on the Port of Alaska, a critical logistics node for the state's supply chain, the research introduced and deployed iFreightOps, a cloud-based platform that combines real-time data ingestion, disruption monitoring, route evaluation, stakeholder communication, and performance forecasting.

iFreightOps incorporates multiple interlinked modules, including a Dashboard for real-time KPI monitoring, a Scenario Analysis engine powered by discrete-event simulation for evaluating disruption impacts, and an Incident Management module that supports both structured incident logging and automated notification dissemination via SMS and email. These components work in concert to help port operators monitor traffic trends, assess routing strategies under disruption scenarios, and maintain operational awareness through transparent, data-driven communication.

To operationalize these insights and support real-time decision-making, iFreightOps was developed as a modular web-based platform tailored to port environments. The Scenario Analysis module uses simulation modeling to assess the performance of alternative routing strategies under various disruption scenarios. This is complemented by the Dashboard and Forecasting tools, which provide short-horizon predictions of key performance indicators to inform day-to-day planning. The Incident Management module supports structured logging, disruption classification, and real-time stakeholder notifications. Together, these capabilities enabled port personnel to respond more effectively to operational disruptions. During deployment at the Port of Alaska, the platform facilitated up to 300 percent reductions in vehicle wait times during incidents and improved scheduling efficiency under normal operating conditions.

The study also introduced a structured framework to assess alternative routes based on operational performance, implementation feasibility, and network versatility. This framework informed a set of prioritized routing recommendations, emphasizing the importance of maintaining at least one viable detour for each disruption-prone segment. This is particularly critical given ongoing infrastructure projects, such as the Alaska rail realignment, that may impact key access points like the Ocean Dock Road rail crossing.

Although developed for the Port of Alaska, the platform's architecture and analytical methodology are transferable to other freight-centric nodes, especially those constrained by limited access, congestion, or infrastructure fragility. Future research could extend the platform's reach to regional corridors such as the Seward and Glenn Highways, supporting coordinated freight resilience at a broader geographic scale.

Planned enhancements include integrating yard-side and vessel-side operations, incorporating agent-based models and reinforcement learning for adaptive traffic control, and adding blockchain-secured audit trails for incident verification. These additions will further strengthen iFreightOps as a comprehensive smart port platform that supports resiliency, scalability, and operational transparency.

In summary, this project delivers a modular, extensible, and operationally grounded framework for improving port performance through integrated analytics. It provides immediate value to port

operators while offering a foundation for broader adoption in logistics networks seeking adaptive and intelligent infrastructure management solutions.

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APPENDICES

Appendix A. Long-term Disruption Simulation Pipeline

Algorithm 1 Long-term Disruption Simulation

Require: Hourly truck counts, hourly car counts, simulation window $[t_0, t_N]$
Ensure: Mean and maximum waiting times; mean and maximum cycle times

Compute arrival rates $\lambda_{\text{truck}}(h)$ and $\lambda_{\text{car}}(h)$
$A \leftarrow \varnothing$ ▷ master list of arrivals
for each hour $h \in [t_0, t_N]$ **do**
    $n_{\text{truck}} \sim \text{Poisson}\big(\lambda_{\text{truck}}(h)\big)$
    $n_{\text{car}} \sim \text{Poisson}\big(\lambda_{\text{car}}(h)\big)$
    Append n_{truck} tuples (Truck, $U(h, h+1)$) to A
    Append n_{car} tuples (Car, $U(h, h+1)$) to A
Sort A by time stamp
Create discrete-event environment $\rightarrow$ *env*
Register resources in *env*: check-in gate, track gate, hazmat lane
for all $(type, t) \in A$ **do**
    VEHICLE(type, t, env)
    Run simulation until t_N
    Extract waiting-time and cycle-time samples
    Compute KPI summary $\rightarrow$ *mean_wait*, *max_wait*, *mean_cycle*, *max_cycle*
    return KPI summary

Algorithm 2 Process LONG-TERM-VEHICLE($type$, t, env)

Hold until t
Request inbound gate; include any train-blocking delay
Travel to yard; duration $\leftarrow$ TravelTime($type, t$)
if $type$ = Truck **then**
    Dwell $\sim$ DwellTime()
    if Bernoulli(p_{hazmat}) **then**
        Request hazmat lane; wait HazmatService()
    if Bernoulli(p_{maint}) **then**
        Wait MaintenanceDelay()
Travel back to exit; duration same as Line 3
Record waiting-time and cycle-time

Appendix B. Short-Term Disruption Simulation Pipeline

Algorithm 3 Short-term Disruption Simulation

Require: Arrival list A; block interval $B = [t_b, t_b + \Delta_b]$; scenario set $\{\text{Normal}, \text{No-Reaction}, \text{Detour}\}$
Ensure: KPI summary for each scenario

for all SCENARIO in $\{\text{Normal}, \text{No-Reaction}, \text{Detour}\}$ **do**
    Reset *env* state and logs
    if SCENARIO = No-Reaction **then**
        never detour
    else if SCENARIO = Detour **then**
        after τ_r switch to alternate route
    for all $(type, t) \in A$ **do**
        env.spawn(VEHICLE(type, t, env, B, SCENARIO))
        env.run(until t_N)
        Extract waiting-time and cycle-time from logs
        Compute $\text{KPI}_{\text{SCENARIO}}$: mean and max of waiting and cycle times
        return $\{\text{KPI}_{\text{Normal}}, \text{KPI}_{\text{No-Reaction}}, \text{KPI}_{\text{Detour}}\}$

Algorithm 4 Process SHORT-TERM-VEHICLE(*type*, *t*, *env*, *B*, SCENARIO)

procedure VEHICLE(type, t, env, B, SCENARIO)
    Hold until t
    if $t \in B$ **then**
        if SCENARIO = No-Reaction **then**
            queue at entry until end(B)
        else if SCENARIO = Detour **then**
            wait τ_r; select alternate route
    Request inbound gate; include any train-blocking delay
    Travel to yard
    if *type* = Truck **then**
        Dwell $\sim$ DwellTime()
        if Bernoulli(p_{hazmat}) **then**
            Request hazmat lane; wait HazmatService()
        if Bernoulli(p_{maint}) **then**
            Wait MaintenanceDelay()
    Travel back via chosen route (request gates as needed)
    Record waiting-time and cycle-time