Optimising heavy cargo traffic management: Enhancing decision-making through effective data management at the Port of Richards Bay

By

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Declaration

I **Lindumusa Justice Nxele** declare that

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Dedication

This dissertation is dedicated to the memory of my late parents, Mr. JR and TA Nxele, who laid the foundation of my academic journey. To my loving wife, Talenta Nxele, and my daughters, Lithalethu and Nhlokomo, this work stands as a testament to the love, support, and sacrifices we made together. To my sister, Dr. Nombuso Nxele, for her relentless belief in me, and to Evangelist Skhakhane for his spiritual guidance. This is also dedicated to every soul who has pushed me, supported me, and believed in me. This achievement is as much yours as it is mine.

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First and foremost, I extend my deepest gratitude to my Heavenly Father, in the mighty name of the Lord Jesus Christ, for granting me the strength, wisdom, and grace to reach this milestone. Throughout the challenges and obstacles that stood in my way, my faith in Him has been my anchor. Without my Lord Jesus Christ, I am nothing; all honour and glory are due to Him.

I dedicate this work to the loving memory of my late parents, Mr. JR and TA Nxele. It is in their honour that this master's dissertation is being done. Their unwavering belief in the power of education sparked the flame of academic excellence in my life. Their legacy of hard work and resilience lives on through this achievement.

To my beloved wife, Talenta Nxele, and my two beautiful daughters, Lithalethu and Nhlokomo: your love, encouragement, and sacrifices have been my constant source of strength. I know I had to steal precious moments from you to pursue this goal, but your unwavering support carried me through. You are my greatest inspiration. There was a particularly challenging period during the drafting of this dissertation when my wife had to relocate to Nkandla for work. We had never lived apart in our union, and she had to leave our daughters behind. This separation was incredibly difficult for our family. During this time, I struggled to write even a single sentence, and I doubted whether I would be able to complete this work. Babysitting our eight-month-old daughter at times while trying to manage my studies was a profound challenge.

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A special note of appreciation goes to the City of uMhlathuze and Transnet. Your cooperation and willingness to grant me access to critical data and reports were critical to the success of this research. Without your support, this study would not have been possible.

Abstract

This study's primary objective was to explore the utilisation of a data management system to optimise and reduce heavy cargo traffic at the Port of Richards Bay. The study was based on the following objectives: first, to analyse current traffic data to understand patterns, congestion points and high impact points, particularly on the N2 and the John Ross Highway, which leads to the Port of Richards Bay; secondly, to explore the feasibility of the use of a designed data management system to optimise heavy cargo traffic flow and alleviate the strain on local infrastructure and services; thirdly, to recommend a system to integrate real-time data collection, visualisation, and communication tools for stakeholders, including the Richards Bay Coal Terminal (RBCT), Transnet, and the City of uMhlathuze traffic authorities.

The study employed a qualitative, desktop-based research methodology using secondary data and a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) (Haddaway, Page, Pritchard, & McGuinness, 2022) systematic literature review to analyse existing studies on traffic management systems and their effectiveness. The PRISMA framework was chosen to ensure a comprehensive and structured review of the data sources. The research questions guiding this study sought to answer the research objectives. Employing these data analysis methods corresponded with the PRISMA framework

The findings of the study reveal current traffic congestion trends pose a constant challenge with negative effects, especially on infrastructure, environment and the overall functioning of the city of uMhlathuze, specifically from the N2 and John Ross Highway, leading to the port. The study points to the possible successful implementation of a developed data management system which will result in Richards Bay's truck congestion significantly reduced, freeing up traffic law enforcement services for other critical tasks while addressing environmental and infrastructural concerns. This study serves not only as a scholarly contribution but also as a practical solution to a pressing issue which has effects on the daily lives the Richards Bay residents.

The study recommended the development of a system to address traffic delays, reduce emissions from idling trucks, and optimise road use to prevent further damage to local infrastructure. In the application, the system tracks heavy trucks using sensors, automatic number plate recognition (ANPR) cameras, and an app that allows truck drivers to check in and monitor their queue positions. By providing real-time updates on truck movements and daily handling capacity, the system aims to reduce traffic congestion, improve decision-making

for traffic authorities, and ease the burden on local traffic law enforcement officials, who are often preoccupied with managing this truck traffic rather than strengthening law enforcement. This study also provides recommendations to address other broader logistics challenges.

Keywords: Heavy Cargo Traffic Management; Data Management Systems; Real-Time Data Monitoring; Decision-Making Optimisation; Port of Richards Bay

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List of Acronyms

4IR - Fourth Industrial Revolution

AI - Artificial Intelligence

AIS - Automatic Identification System

ANPR - Automatic Number Plate Recognition

App - Application

AT-Conv-LSTM - Attention-based Convolutional Long Short-Term Memory model

BDA - Big Data Analytics

CAUDUS - Congestion Alleviation Using Dynamic and Utility-driven Scheduling

C-ITS - Cooperative Intelligent Transportation Systems

DBMS - Database Management System

DDDM - Data-Driven Decision-Making

DF - Data Fusion

DSS - Decision Support Systems

DST - Decision-Support Tool

EC - Evolutionary Computation

FMS - Fleet Management System

FMS - Future Mobility Sensing

GHG - Greenhouse Gas

GPS - Global Positioning System

GRU - Gated Recurrent Unit

IDSS - Intelligent Decision Support Systems

IoT - Internet of Things

IOU - Intersection over Union

ITS - Intelligent Transportation Systems

ITMS - Intelligent Traffic Management Systems

KZN - KwaZulu-Natal

LSTM - Long Short-Term Memory (a type of neural network model)

MOT - Multi-Object Tracking

MOT - Multi-Object Tracking

N2 - National Route 2

PC - Personal Computer

PCS - Port Community System

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RDBMS - Relational Database Management System

RFID - Radio Frequency Identification

RBCT - Richards Bay Coal Terminal

SLR - Systematic Literature Review

STMP - Smart Traffic Management Platform

TAS - Traffic Allocation System

TAS - Truck Appointment System

TFA - Traffic Flow Analysis

TEN-T - Trans-European Transport Network

Transnet - Transport Network (Refers to South Africa's state-owned logistics company)

UMhlathuze - Refers to the city of uMhlathuzeWSN - Wireless Sensor Network

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Chapter One: Introduction

1.1 Introduction

The Book of Nahum in the Bible offers a vivid image that can be interpreted as resonating with modern technological advancements. Nahum describes chariots speeding through the streets, clashing against one another and blazing like torches, lighting up the roads. While these "chariots" were limited by the prophet's understanding of his time, they could metaphorically represent present-day vehicles and the fast pace of modern life, highlighting humanity's ongoing journey of innovation and transformation.

Today, we live in the era of the Fourth Industrial Revolution (4IR), marked by technological breakthroughs such as artificial intelligence, machine learning, and big data analytics. These innovations have significantly altered how societies function, offering tools that not only process vast amounts of information but also drive critical, evidence-based decision-making. Throughout history, data has been a silent force behind human advancement, though not always formally recognised or categorised. In the 4IR context, the structured use of data has become vital for progress, especially for developing economies seeking to overcome longstanding developmental challenges.

In South Africa, One area facing urgent operational inefficiencies is the Port of Richards Bay, located in the City of uMhlathuze in KwaZulu-Natal Province. As Africa's largest coal export hub, the port plays a critical role in national and regional logistics. However, it suffers from recurring problems such as congestion caused by heavy cargo trucks and outdated traffic management systems. These inefficiencies hinder both daily operations and long-term strategic planning.

The integration of 4IR technologies, particularly advanced data management systems, holds great potential for resolving these issues. Real-time data processing and analytics can provide visibility into port operations, enabling authorities to manage cargo traffic more effectively, minimise congestion, and make timely, informed decisions that enhance efficiency.

This study investigates how integrated data management systems can be leveraged to optimise heavy cargo traffic management at the Port of Richards Bay. The research aims to enhance operational decision-making through the implementation of real-time, data-driven strategies that improve the movement of goods and reduce delays. A desktop methodology was used to conduct a comprehensive literature review on smart city frameworks, port logistics, and data-based decision-making in similar high-traffic port environments.

The findings of this study are expected to contribute toward developing a practical framework for managing cargo flows more efficiently at Richards Bay. By optimising operations through enhanced data utilisation, the port can improve turnaround times, reduce costs, and strengthen its appeal as a regional logistics hub. In doing so, it can not only boost trade efficiency but also support broader economic development objectives for South Africa.

1.2 Research Problem Statement

In the mid-1970s, the natural lagoon along South Africa's east coast in Northern KwaZulu-Natal was transformed into the Port of Richards Bay, a deep-water facility officially opened in April 1976 to serve as the country's largest bulk export terminal. Designed primarily for coal exports, the port was intended to operate in tandem with South Africa's rail network, connecting inland mining operations to global markets through efficient freight corridors (KwaZulu-Natal Department of Transport Freight Transport Data Bank, 2003). Companies such as Mondi and Alusaf (now South32) benefited from this vision, which placed Transnet at the centre of managing and maintaining the national rail infrastructure.

However, over the years, this vision faltered. Chronic underinvestment, poor governance, and extensive vandalism contributed to the deterioration of South Africa's rail network (Makhaye, 2023). As rail capacity collapsed, the freight burden shifted to road transport, an infrastructure never designed to accommodate such volumes. Global shifts in coal demand, particularly following geopolitical disruptions such as the Russia-Ukraine conflict, further accelerated this shift (Banya, 2023). Today, as many as 50,000 heavy-duty trucks converge on the Port of Richards Bay each month, creating overwhelming congestion on the N2 and John Ross Highway.

The surge in road-based freight has had cascading effects: local infrastructure is buckling under the weight of excessive loads, communities face growing safety risks, and environmental degradation is accelerating. High-profile incidents, such as the tragic 2023 crash on the N2 near Pongola, which claimed 21 lives, including schoolchildren, underscore the severity of the crisis (Makhaye, 2023). Attempts by local authorities to mitigate the risks, including rerouting trucks and issuing traffic alerts, have proven largely ineffective due to the absence of a coordinated, data-driven system capable of managing real-time truck flow and port access.

At the heart of this systemic failure is a critical data management gap. There is currently no real-time scheduling or queuing system at the Port of Richards Bay to monitor or regulate truck arrivals. As a result, trucks often queue for days on arterial roads, creating hazardous

bottlenecks and impeding law enforcement's ability to manage broader traffic concerns. Transnet, the port authority, remains reliant on ad hoc notifications from traffic officers rather than predictive or integrated data systems. This lack of a unified, intelligent traffic coordination framework has made effective decision-making virtually impossible in the face of growing logistical demands.

This study therefore aims to investigate how integrated data management systems can be used to optimise heavy cargo traffic management at the Port of Richards Bay. The research explores the potential of data-driven solutions, particularly those enabled by Fourth Industrial Revolution (4IR) technologies, to enhance operational decision-making and alleviate port congestion. By examining the root causes of the current crisis, including the shift from rail to road, this study proposes a framework for incorporating real-time data insights into traffic control, queuing mechanisms, and port scheduling systems.

The anticipated contribution of the study is twofold: first, to highlight the urgent need for digital infrastructure capable of monitoring and managing cargo traffic in real time; and second, to provide evidence-based recommendations that can support the port's transition toward more efficient and safer logistical operations. In doing so, this research fills a critical knowledge gap in South Africa's freight and logistics discourse, offering practical insights into how data can drive resilience and innovation in port management.

1.3 Research Aims and Objectives

1.3.1 Aim of the Study

The aim of the study was to explore the utilisation of data management to optimise and reduce heavy cargo traffic at the port of Richards Bay.

1.3.2 Research Questions

How can data management be used to improve decision-making and alleviate the movement of heavy cargo trucks at the Richards Bay port?

i. What are current traffic data patterns, congestion points and high impact points, particularly on the N2 and the John Ross Highway, which leads to the port of Richards Bay?
ii. What is the feasibility of the use of a developed data management system to optimise heavy cargo traffic flow and alleviate the strain on local infrastructure and environment?

iii. What strategies can be recommended to develop a system to integrate real-time data collection, visualisation, and communication tools for stakeholders, including the Richards Bay Coal Terminal (RBCT), Transnet, and the City of uMhlathuze traffic authorities?

1.4 Research Objectives

The following were the objectives of the study:

i. To analyse current traffic data to understand patterns, congestion points and high-impact points, particularly on the N2 and the John Ross Highway, which leads to the Port of Richards Bay.
ii. To explore the feasibility of the use of a developed data management system to optimise heavy cargo traffic flow and alleviate the strain on local infrastructure and environment.
iii. To recommend a system integrating real-time data collection, visualisation, and communication tools for stakeholders, including the Richards Bay Coal Terminal (RBCT), Transnet, and the City of uMhlathuze traffic authorities.

1.5 Rationale (Motivation)

The John Ross Highway (R34) serves as a vital corridor, linking the N2 national route to the Port of Richards Bay. This highway facilitates the movement of goods between the port and inland regions, playing a critical role in South Africa's logistics and trade. The map provides a visual representation of this route, offering insight into the transportation infrastructure supporting the port's operations.

Figure 1: A map highlighting the John Ross Highway (R34) and its connection to the Port of Richards Bay.



Source: (Google Maps, 2024)

Figure 2: Heavy Cargo Trucks on the John Ross Highway in Richards bay lining up to the Port of Richards Bay



Source: Times Live News (2023)

The motivation for conducting this research stems from the growing challenge of managing heavy cargo traffic at Richards Bay Port, especially given the limitations observed in current decision-making and information management practices. The practical need to address data-driven decision-making for traffic management in the port's vicinity motivates this study. Heavy cargo trucks carrying coal have increased traffic on the main roads leading to Richards Bay Port, particularly on the N2 and John Ross Highway paths, necessitating a coordinated strategy for efficient traffic control management.

Current research suggests that optimised data management can be critical in enhancing decision-making processes in various industries, yet its application within public-sector traffic management remains underexplored (Tawil et al., 2024). This study aims to fill this gap by investigating how a unified data management system can improve real-time traffic monitoring and enable coordination among players, such as the Richards Bay Coal Terminal (RBCT), Transnet, and the City of uMhlathuze traffic authorities.

The study aims to examine traffic data to identify congestion areas and consider the possibility of introducing a data management system that integrates real-time visualisation and communication tools in a proposed solution plan. Furthermore, the research intends to shed light on how organised data management can enhance efficient decision-making processes to enhance service quality, manage traffic flow, support infrastructure utilisation, and alleviate impacts. The results aim to offer suggestions for a data system that can ease the congestion of cargo loads and enhance operational efficiency and collaboration among stakeholders eventually.

The study thus aims to examine the potential of a data management solution to improve heavy cargo traffic flow, mitigate congestion, and streamline communication among key stakeholders, including the Richards Bay Coal Terminal, Transnet, and local traffic authorities. By focusing on academic and practical gaps, this research intends to contribute to the broader discourse on data-driven coordination and infrastructure management decision-making. The anticipated findings and recommendations aim to inform strategies for enhancing the port’s operational efficiency, which is essential for positioning it as a key player in South Africa’s economic landscape.

Addressing these gaps, this study will explore patterns and congestion points on critical routes, assess the feasibility of a developed data management system for real-time heavy cargo traffic optimisation, and provide recommendations for a system that integrates data collection,

visualisation, and communication tools. Through this approach, the study seeks to assess whether such a solution can be effective, contributing to the literature on data-driven approaches to infrastructure challenges in port organisation.

1.6 Significance of the Study

This study acknowledges that the Richards Bay port alone cannot resolve the complexity of truck congestion. A collaborative framework is essential to ensure that all stakeholders have access to the data management system, enabling them to see data about expected traffic volumes and make informed, coordinated decisions. The study will develop a system that not only serves the city but also provides valuable insights to other stakeholders, thereby fostering a unified approach to heavy cargo traffic management.

The significance of this research lies in its potential to create a sustainable and scalable model for traffic management that benefits all parties involved. By incorporating data management, the system will enable stakeholders to anticipate traffic conditions and take initiative-taking measures to prevent congestion, ultimately leading to smoother operations.

1.7 Structure of the Dissertation

The study is divided into five chapters, each with a specific focus aligned with the qualitative, desktop-based study approach, utilising a PRISMA systematic literature review.

Chapter One: Introduction

This chapter introduces the research topic, outlining the core research questions that guide the study in alignment with its aims. It also addresses the study's delimitations, focusing on heavy cargo traffic management at the Port of Richards Bay.

Chapter Two: Literature Review

Chapter two provides a systematic review of literature relevant to the study, applying the PRISMA method. The literature review process involves rigorous screening and selection to ensure that only the most relevant studies inform the research, offering a comprehensive foundation for the analysis.

Chapter Three: Research Methodology

This chapter details the qualitative, desktop study approach used for the research. It covers the PRISMA-based systematic literature review methodology, explaining the rationale behind document selection, data collection from secondary sources, and data quality control. Ethical considerations related to the use of secondary data are also addressed.

Chapter Four: Findings and Discussion

Chapter four presents and discusses the findings based on the reviewed literature. The qualitative data gathered through the PRISMA method is presented in a synthesised format, organised to address the study's research questions and offer insights into heavy cargo traffic management challenges at the Port of Richards Bay.

Chapter Five: Conclusions and Recommendations

In this final chapter, the key findings are summarised, with recommendations drawn to address the study's objectives. Suggestions for future research are also included, focusing on areas for further exploration within heavy cargo traffic management and data-driven solutions at Richards Bay

1.8 Conclusion

The growing traffic congestion and operational inefficiencies associated with handling heavy cargo at Richards Bay Port underscore the need for effective data management solutions. This research leverages the advancements of the Fourth Industrial Revolution (4IR) to address these issues, exploring a data-driven strategy that enhances cargo movement and alleviates the strain on local infrastructure. The study focuses on integrating real-time data collection, visualisation, and communication tools to enhance decision-making among key stakeholders, including the Richards Bay Coal Terminal (RBCT), Transnet, and City of uMhlathuze traffic authorities.

This research is important not for recognising traffic patterns and high-impact congestion areas but for evaluating the viability of establishing a cooperative and strategic planning system. By adopting a data management system to address traffic flow at the port, this research intends to propose actionable insights and practical strategies that stakeholders can use to manage and prevent bottlenecks effectively. The expected results of this research will enhance the traffic

control system in Richards Bay. Help boost South Africa’s infrastructure by improving the flow of heavy cargo vehicles and ensuring safer and more effective operations.

Chapter Two: Literature Review

2.1 Introduction

The Port of Richards Bay, the country's largest export hub, is facing congestion issues caused by a rise in heavy truck traffic volumes. Initially, the port relied on a developed rail system for goods transport, but the disruption of this railway network forced industries to shift to road use, leading to operational inefficiencies and straining road infrastructure. The increase in truck traffic due to coal demand has worsened congestion, particularly on the N2 and John Ross Highway, negatively impacting logistics and local communities. This study aims to optimise the management of heavy cargo traffic at the Port of Richard's Bay by enhancing decision-making processes through effective data management strategies. By following the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta Analyses), this study conducts a review of literature to uncover practices and technologies for monitoring truck movements and easing congestion. Additionally, it seeks to enhance real-time coordination among stakeholders, like Transnet, Richards Bay Coal Terminal, and the City of uMhlathuze. We will use the results to develop a data system that enhances heavy cargo traffic flow and reduces congestion at the port and its surrounding areas.

This systematic review investigates how effective data management can optimise heavy cargo traffic at the Port of Richard's Bay. Key objectives are to enhance decision-making processes to alleviate heavy cargo traffic congestion. The review examines theories such as queue theory, traffic flow theory, and data-driven decision-making theory and synthesizes empirical studies on data management for traffic optimisation. A systematic literature search was conducted using specific search queries to identify relevant articles. The review concludes with a summary of findings and recommendations for further research.

2.2 Background

Founded in 1976 with a focus on handling shipments like coal for trade purposes, Richards Bay Port has grown into an important economic centre on South Africa's east coast, benefiting both the local region and the nation (Africa Ports, 2004). The initial plan for the port was to utilise South Africa's existing rail network to move goods from mining areas like Mpumalanga to the Port of Richards Bay. Over time, issues such as management and theft have exacerbated Transnet's rail infrastructure, resulting in a decrease in its capacity to meet the increasing demand for goods transportation. The deterioration in rail infrastructure has compelled industries to rely more on road transport, resulting in an increase in the usage of heavy cargo trucks. Every month, around 50,000 trucks arrive at Richards Bay, putting strain on the N2 and

John Ross Highway, which was not initially built to handle such traffic volumes, causing congestion and damage to the infrastructure while also contributing to a rise in road accidents (Carte Blanche, 2023).

The transition from rail to road transport presents a variety of challenges that go beyond traffic issues. Increased heavy cargo truck traffic has not only led to delays in transportation but has also put a strain on local infrastructure and raised safety concerns for communities residing along these major highways. Regulating truck traffic in the City of Umhlathuze has seen limited effectiveness. Events such as the conflict in Ukraine are exacerbating the situation due to the ongoing demand for coal transport. This research focuses on the importance of using a data-driven approach to handle the large volume of heavy cargo traffic at Richards Port more efficiently. This approach aims to enhance decision-making using data management systems, thereby alleviating truck congestion and improving port operation efficiency.

This research study reviewed existing literature, utilising the PRISMA framework, to explore the role of data management in optimising heavy cargo traffic management. The study addresses enquiries concerning the design, development, and implementation of a data management system that can enhance decision-making, facilitate real-time monitoring capabilities, and promote cooperation among key stakeholders, like Transnet, Richards Bay Coal Terminal, and the city of uMhlathuze traffic officials. The aim is to develop a system that can assist in providing data for decision-making, thereby reducing heavy cargo traffic congestion, enhancing vehicle movement, and addressing safety and structural issues arising from the increase in truck traffic.

The research aims to enhance real-time cargo traffic optimisation by studying traffic management solutions and data management approaches. The findings of this analysis will guide the creation of a system for streamlining truck movements through an integrated data management system that incorporates data inputs such as road sensors and ANPR cameras.

2.3 Research Problems

The Richards Bay Port, which previously relied on railways for exporting goods, is currently grappling with numerous heavy cargo truck traffic issues due to the deterioration of the railway system. Heavy cargo coal trucks are causing congestion on local roads, posing safety hazards, and causing infrastructure damage. This research study investigates practical solutions based on data to enhance the management of heavy cargo traffic and make better decisions aimed at easing congestion problems at the N2, John Ross Highway, and the port.

2.4 Research Methods

The review followed the PRISMA method, systematically identifying, selecting, and critically evaluating relevant studies. A comprehensive literature review from the past seven years was undertaken

2.5 Eligibility Criteria

The criteria for choosing the research papers for this study included their focus on data management systems for heavy cargo traffic control and congestion reduction, their English writing, their publication in peer-reviewed journals from 2018, and their classification as research articles. The following criteria were used to exclude the research papers: Articles that were duplicates. There were articles that discussed data management in relation to several types of traffic. Articles published in languages other than English. Articles published prior to 2018. Conference papers and book chapters. Editorial letters and reviews. Conceptual papers were also excluded and articles that prioritised simulations over real-world data. The study upheld a level of scrutiny by excluding publications that did not meet these standards from consideration.

2.6 Information Sources

The research used two electronic databases: Google Scholar and the UKZN Library. The filtering tools provided by both Google Scholar and UKZN Library were used to identify items according to the eligibility criteria while providing access to additional scholarly resources aligned with the scope of the study.

2.7 Search

The search strategy for this study used Google Scholar and the University of KwaZulu-Natal's (UKZN) Library as primary research platforms to identify relevant studies. Specific search terms included "data management in transportation," "heavy cargo traffic in Richards Bay," "truck congestion at ports," "traffic flow optimisation strategies," "road transport and logistics," "transport optimisation techniques," "traffic monitoring systems for freight transport," "decision-making in freight transport management," "freight transport challenges in South Africa," and "congestion management solutions." Boolean operators like AND OR were applied to narrow down the search results, such as "heavy cargo traffic AND Richards Bay logistics" and "traffic flow OR congestion management AND freight transport." Filters were applied to prioritise peer-reviewed journal articles, conference papers, and reports published between 2018 and 2024. The search specifically targeted studies related to the Richards Bay

area and broader South African logistics contexts to ensure the relevance of the findings to the study's objectives. The UKZN Library was also utilised to verify the credibility of selected literature and ensure its scholarly reliability. After an initial screening of titles and abstracts, a manual review process removed duplicate studies, identifying studies for further examination. The results were exported to EndNote.

2.8 Study Selection

The researcher selected the papers for this study by considering their relevance to data management systems used for managing heavy cargo traffic and reducing congestion at the Port of Richards Bay. The researcher resolved any doubts about a study's relevance by conducting a review and aligning it with the research objectives. This review included only studies that met the inclusion criteria and addressed the research questions.

2.9 Data Extraction

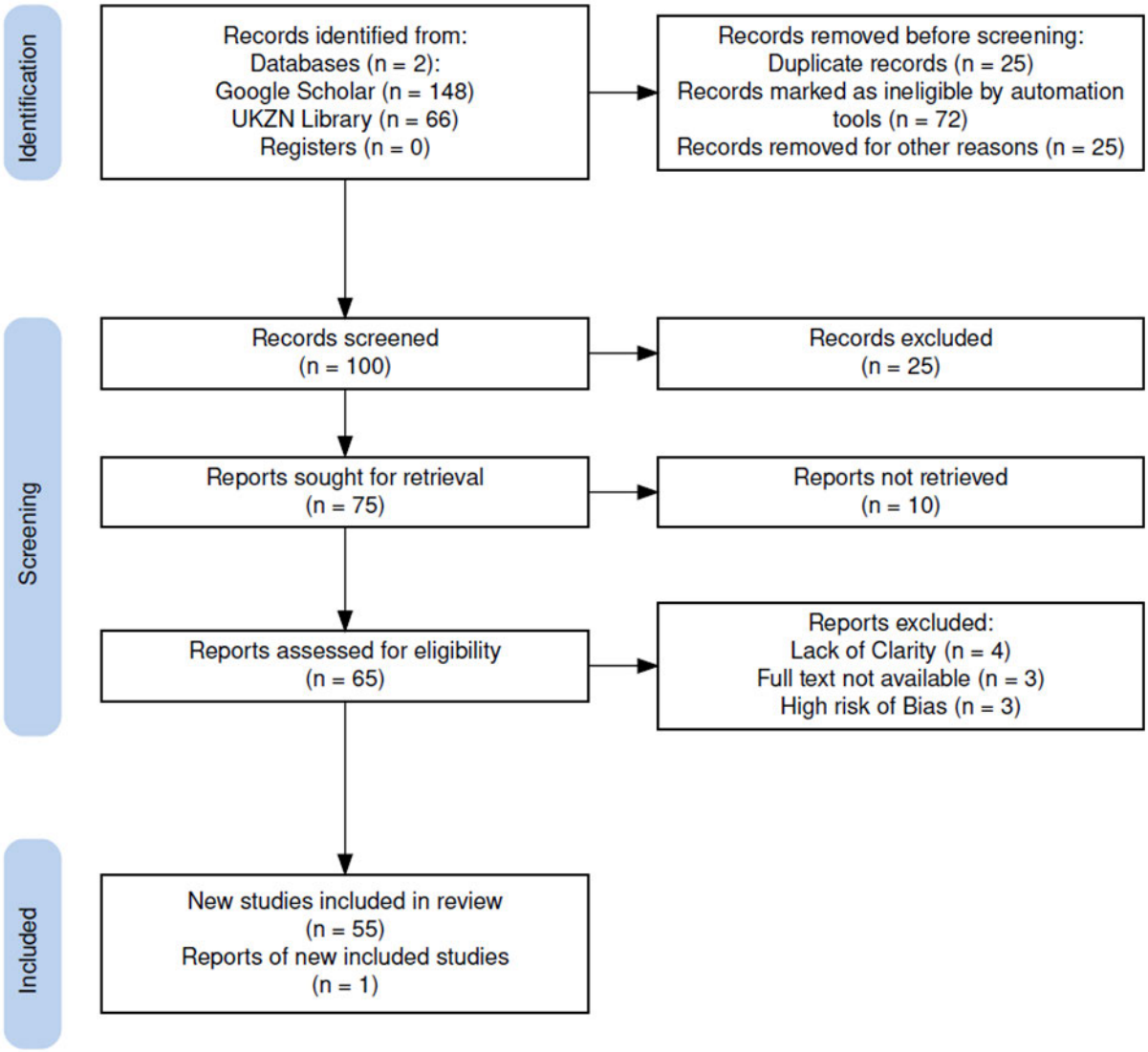
EndNote was used to organise and manage all collected articles and publications. These materials were stored in a dedicated folder on the UKZN Microsoft OneDrive platform for retrieval and assessment purposes. The extracted data from each study encompassed aspects such as author details, publication year, country of origin, study objectives, type of data management system, traffic management focus, analytical techniques, congestion metrics, data sources, outcomes, key findings, and recommendations for future work. Any discrepancies or missing information were noted for follow-up analysis, ensuring a comprehensive understanding of each study's contribution to the topic.

2.10 Results

Study Selection

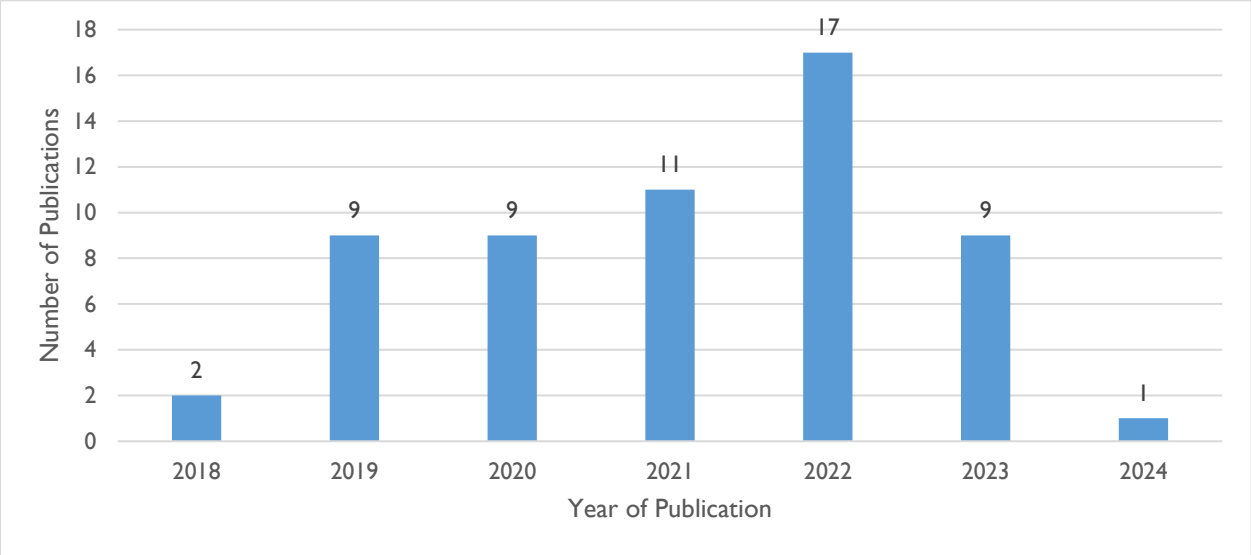
Figure 3 presents a flowchart that illustrates the selection process in accordance with PRISMA guidelines. A total of 214 articles were found, but 25 were duplicated papers, and others marked as ineligible were 72. After their removal, 117 studies were screened by title and abstract, and 25 were excluded because they were irrelevant to the study. The remaining 92 papers were selected for full-text screening. Of these articles, 38 were excluded. Ultimately, the review deemed 55 papers eligible for inclusion.

Figure 3: PRISMA Diagram



The review included studies that specifically examined factors contributing to the optimisation of heavy cargo traffic management and data-driven decision-making at Port Richards Bay, focusing on publications from 2018 to 2024. The exclusion criteria included non-peer-reviewed sources, studies not published in English, studies published before 2018, unreputable studies, and studies that were irrelevant to the research focus on heavy cargo traffic management and enhancing decision-making using effective data management strategies.

Figure 4: Year and Number of Publications



The selection of articles analysed in this PRISMA review spans from 2018 to 2024.

The year 2019 saw a rise in the number of published studies, with 9 additions to the growing body of literature.

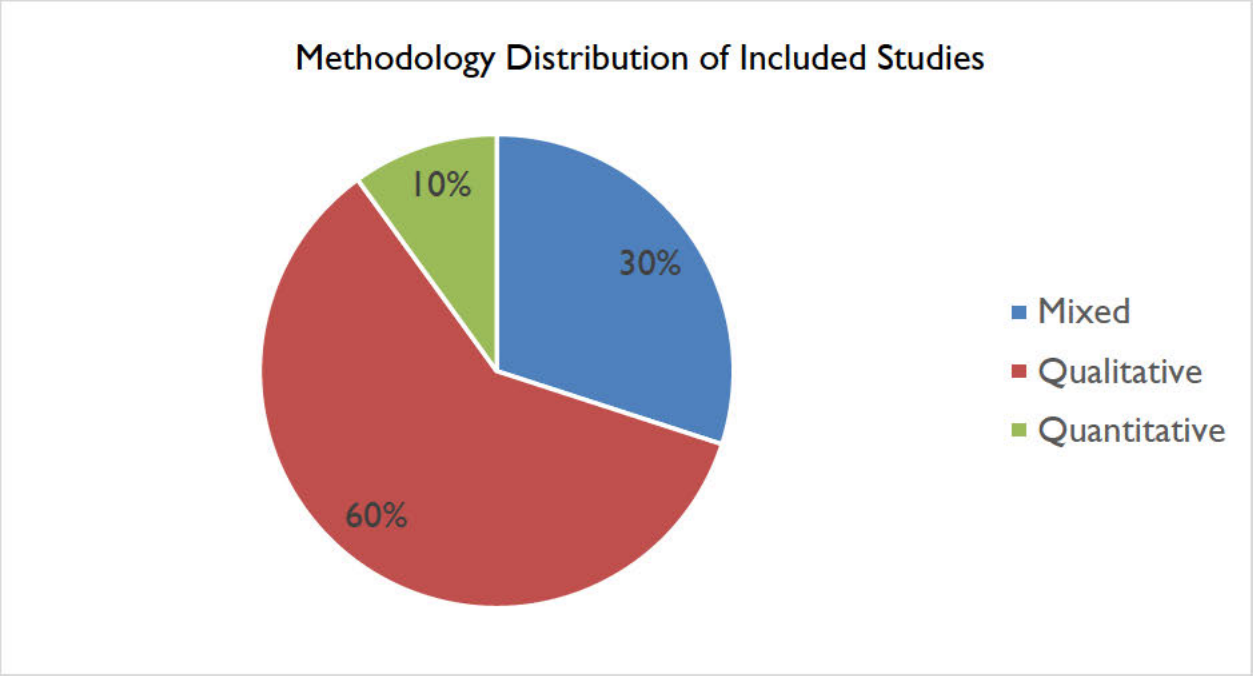
In both 2020 and 2021 years, at the height of Covid-19, activity levels were observed with 9 publications in 2020 and 11 in 2021.

The year 2022 saw a rise in research activity with 17 studies dedicated to the topic area, suggesting a heightened interest in exploring avenues within the field of heavy cargo management utilising data and sensor technologies.

In 2023, 9 publications were documented indicating a level of interest, with a decrease from the peak observed in the previous year.

These conclusions are based on bibliometric analyses and increased funding priorities, reflecting a strategic alignment of research with societal needs. One publication in this field was identified in 2024, indicating ongoing research. The focus of recent studies appears to emphasize subjects or practical applications of established systems, building on prior research. The outcomes of these studies align with an ongoing interest in improving traffic control through data-driven methods. The number of publications may vary due to various factors, such as the availability of resources, research priorities, or advancements in related technologies. However, further evidence is necessary to definitively determine the specific reasons for these variations.

Figure 5: Methodology Distribution of Included Studies



The scoping review found factors that encourage the adoption of technology to enhance heavy cargo traffic management in Richards Bay. Stakeholders contribute to this process by considering factors such as meeting requirements and industry standards, while also collaborating with transport authorities. Conversely, obstacles like infrastructure costs and lack of immediate access to traffic data hinder progress. Moreover, cultural elements such as hesitance towards embracing technologies and sticking to ways of operation impact the implementation process significantly. Technological advancements are significantly influenced by factors such as the ease of integration with other systems and concerns about data security. Furthermore, external factors such as the state of transportation infrastructure, the availability of resources, and the reliability of communication networks in various areas significantly impact the effectiveness of traffic management solutions.

2.11 Discussion

In the comprehensive analysis of 55 research papers, the efficiency of managing heavy cargo traffic in the Port of Richards Bay was examined, as were factors influencing this process and the strategies suggested by each study's author. By looking at these proposed solutions by past authors the study aimed to tackle the aspects that affect the acceptance of real time data management systems and traffic control technologies. The goal is to develop a more inclusive method, for easing the heavy cargo traffic of Richards Bay Port while enhancing decision making and enhancing overall traffic management.

2.11.1 Queuing Theory

Operations researchers use queueing theory, a mathematical model, to predict and solve issues related to waiting lines or queues. A queueing model is constructed to predict queue lengths and waiting times, thereby easing traffic flow. Queuing theory is an important theory that plays a role that is critical in the management of heavy cargo traffic, especially in places where there is extremely high congestion, and the resources that are available in such places are limited, just like the Port of Richards Bay.

Modi et al. (2019) assert that queuing theory plays a critical role in traffic management by accurately gauging the intensity of traffic, which encompasses the arrival rate of vehicles and the speed at which they receive services. It is known that high traffic intensity always leads to longer queues, and therefore, wait time for trucks is increased, especially at critical points like the entry gate, the toll booths, and the zones where loading and unloading are conducted. Hu, Zhao, Zhu, and Jiang (2019) presented a queuing theory model that provides a deep insight into how the traffic circulation system operates. These models are particularly useful when capturing the accumulation of cargo truck queues and the time it dissipates. Their research discovered that when trucks arrive at the port in excessive numbers during peak hours, queuing theory can be used to form a model on traffic spillback that suggests how to prevent the system from entering excess congestion.

2.11.2 Traffic Flow Theory

Effective traffic flow management is very important when optimising heavy cargo traffic. Traffic flow involves the study of the movement of the drivers of vehicles between two points and how they interact with one another in this process (Menelaou, Timotheou, Kolios, & Panayiotou, 2021). Traffic flow theories describe how the interaction among vehicles, drivers, and main infrastructure on the road, like markings and signs, helps aid the free movement of traffic. This theory is useful for traffic prediction and management.

Some recent research has proven how effective predictive models are in managing traffic flow, especially when it comes to heavy cargo vehicles. Samonte et al. (2022) introduced a traffic flow model, the AT-Conv-LSTM model, which effectively addresses traffic flow issues and provides accurate predictions by combining environmental and social media data. Their research revealed that combining long short-term memory (LSTM) models with additional datasets improves accuracy, a critical factor in managing traffic congestion. According to Wang et al. (2020), the understanding of both spatial and temporal patterns in traffic flow is

important in effectively managing heavy cargo traffic. This traffic flow model helps improve predictive accuracy while managing complex cargo routes.

2.11.3 Data-Driven Decision-Making Theory

When it comes to heavy cargo traffic management, data-driven decision-making (DDDM) is highly effective as it uses a large volume of data to enhance the efficiency of its operations. The theory of data-driven decision-making (DDDM) can be defined as the use of facts, data, and metrics to guide decisions that align with business objectives and goals (Sevidova, Salnikov & Kalinichenko 2023). An important and effective aspect of DDDM is the implementation of intelligent decision support systems (IDSS) into its services. Bolodurina and Speshilov (2023) state that IDSS is particularly useful in improving the cargo flow management system, as it automates route selection and helps minimise risks through its fuzzy logic rules and data modeling techniques.

DDDM has made significant advancements, enabling the effective use of unsupervised learning and deep reinforcement learning for smart traffic management. Nallaperuma et al. (2019) presented a DDDM system that utilises a smart traffic management platform (STMP) to manage large data streams and enhance traffic control decisions. This is very applicable in ports with large cargo traffic, as it will help reduce congestion and prevent delays in the movement of goods.

2.11.4 Intelligent Traffic Management Systems (ITMS) Theory

ITMS theory is based on the concept of real-time data collection, analysis, and decision-making for superior traffic flow and intelligent decision-making for difficult traffic environments. The ITMS theory involves emerging technology: Global Positioning Systems (GPS), Wireless Sensor Networks (WSN), Automatic Number Plate Recognition (ANPR), and Internet of Things (IoT) for the real time and precise monitoring of movement, speed, and spatial dispersion of vehicles (Chavan et al., 2021).

Repositioning systems are useful for determining location and for route optimization. They provide the means for authorities to pinpoint bottlenecks, monitor congestion, and efficiently use roads in real time (Li et al., 2022). If integrated with the map matching system, the precision of the GPS data can be improved, which means that the movement of the trucks can be traced accurately even in the areas where the signal is either obstructed or very strong (Zheng et al., 2020). These technologies are at the heart of delivery models like geofencing, dynamic rerouting, surge pricing and traffic prediction.

Wireless Sensor Networks (WSNs) are used for monitoring traffic flow and vehicle type along with road conditions are critical phase in traffic system. Devarakonda et al. (2018) maintain that WSNs integrated into motorways can supply coarse-grained information about the traffic situation and predict traffic congestion. In a cloud-based network, these sensors communicate high-frequency data to central systems over based protocols like MQTT (Message Queuing Telemetry Transport), and TCP/IP for connectivity of field devices and control centres (Kuftinova et al., 2022).

ANPR technology that reads the license plates and compares them with vehicle registration databases is another important part of ITMS. This is important for access control, enforcement of traffic laws, and monitoring of unauthorized or unscheduled entries in high traffic areas such as port terminals (Lau et al., 2022). When allowed in real-time dashboards, ANPR data assist traffic authorities and port managers to choose entry lines for priority, manage operations at the gates, and track trucks that might avoid check-in systems (Lee et al., 2020).

Additionally, ITMS typically integrates the Decision Support Systems (DSS) and Artificial Intelligence (AI) analytics to improve operational agility. Such systems are based on the machine learning algorithms that enable to forecast congestion, to suggest trucks to be diverted, and to organize the running of the truck traffic from up-to-date data on traffic situation (Bolodurina& Speshilov, 2023). A study by Chen et al. (2021) observed that AI integration with ITMS framework can reduce latency in traffic response and promote efficiency in freight corridors.

2.11.5 The Role of Data Management in Traffic Optimisation

Heavy cargo traffic management is critical in facilitating a seamless transportation process for goods through a port. An efficient cargo management system guarantees timely delivery of goods and enhances the overall performance of port operations. Due to the benefits of this smooth process for cargo transportation in ports, issues relating to heavy cargo have become a point of focus for port authorities and those involved in coordination.

Due to the recent increase in cargo traffic complexity, data management has become a key for optimising cargo traffic in ports. According to Gattuso and Pellicano (2023), an efficient data management system enables real-time monitoring, facilitating swift decision-making to mitigate or reduce traffic, while also facilitating the scheduling of vessels for loading and unloading operations. Jia, Meng, and Kuang (2021) emphasised the importance of optimising heavy cargo traffic in ports to facilitate easy movement of goods. They developed an

optimisation model that balances efficiency and equity in vessel traffic scheduling and handling, significantly contributing to the smooth operation decisions made in ports.

Recent technological advancements, including the development and integration of artificial intelligence (AI), the Internet of Things (IoT), and cloud computing, have significantly enhanced real-time traffic monitoring and control, according to a study by Yu et al. (2022). Despite the introduction of AI as a concept in the 1940s and 1950s, recent technological progress has made its application in areas like traffic management more prominent and sophisticated. Therefore, their study proposed an optimisation model that integrates both geographical data and navigation rules to plan unmanned ship paths, thereby reducing human errors and enhancing safety. Another study by Nadales, Peña, Limón, and Alamo (2023) proposed a solution that uses a two-step technique to plan trips for vessels by taking into consideration time-varying conditions, which further highlights the importance of data management in operation efficiency and safety in general.

2.11.6 Challenges in Heavy Cargo Traffic at Ports

Despite the advancement of traffic management systems, managing heavy cargo traffic at various ports worldwide still presents certain challenges. Most of these challenges are in the form of congestion, delays, and environmental concerns, which directly affect the smooth operation of cargo traffic at ports. Carrer, Ferson, and Green (2020) primarily attribute the challenges to the continuous increase in cargo volume and size, which overwhelms the infrastructure that has been in place at these ports for many years. For instance, Zubkov, Ryazanova, Chebotareva, Bakalov, and Gordienko (2019) conducted a study that identified bottlenecks in the operations of heavy traffic railways that connect ports in the Azov-Black Sea Basin. They discovered that upgrading the infrastructure and technological innovations serving this location is necessary, as it is a major cause of the heavy traffic in this location. They underscored that implementing this upgrade to manage the rapidly increasing export cargo volume will undoubtedly facilitate the unobstructed flow of cargo traffic.

The emissions from cargo-handling vehicles pose a major challenge to the environmental impact of port activities. Ilio, Giorgio, Tribioli, Bella, and Jannelli's (2021) study proposes the development and adoption of hydrogen-fueled yard trucks as a solution to the emissions and operation costs associated with diesel-powered trucks. In addition to environmental factors, poor interaction among different modes of transportation at the port presents other significant challenges. In their research, Shvetsov and Dondokov (2021) suggested the implementation of

a mathematical model to optimise the interaction between road and sea transport, thereby reducing idle time for both vehicles and ships.

2.11.7 Technological Solutions for Traffic Management

Technologically driven solutions play a critical role in effectively managing heavy cargo traffic in ports, particularly in large coordination hubs like the Port of Richards Bay. An example of this technological solution can be the integration of intelligent decision support systems (IDSS) and real-time data analytics. Sevidova et al. (2023) discovered that this technological innovation will help to optimise traffic flows as it makes decision-making for processes of handling cargo movement easier. According to a study conducted by Bolodurina and Speshilov (2023), they discovered that when intelligent decision support systems that use algorithms to automate cargo transportation are properly utilised, it drastically improves the efficiency of flow in cargo management.

Chen, Sun, Chang, and Lin (2021) demonstrated in another study that the incorporation of big data from traffic Internet of Things (IoT) infrastructure allows accurate forecasting of cargo travel time, thereby enhancing coordination management by making it easier and more efficient. Through this innovation, companies can predict and track travel time and, therefore, adjust accordingly to the traffic situation as necessary to reduce delays and avoid congestion.

2.11.8 Impact of Traffic Management on Port Efficiency and Economy

Effective traffic management directly impacts port operations and the economic outcome of their activities, especially in large ports like the Port of Richards Bay. Prokudin et al. (2022) indicated in their study that proper traffic management optimisation through effective techniques like the proportional redistribution technique can enhance freight transport efficiency by up to 25%. In cases of ports that handle large cargo volumes, this means they can achieve faster turnaround time, reduced congestion, and improved operation efficiency in the port.

Improving traffic management boosts operational efficiency in ports and contributes to wider economic outcomes. A study conducted by BolodBolodurina and Speshilov (2023) underscored the significance of risk reduction in cargo transportation through effective decision-making systems. They noted that ease of cargo movement lowers transportation costs, and when goods become more affordable, customers will make more purchases, thereby boosting the economy of the surrounding regions. Ports with an optimised traffic management system usually experience less disruption, which leads to increased customer satisfaction. A

study by Dzemydiene, Burinskiene, and Miliauskas (2021) emphasised multi-criteria decision support systems' role in cargo transportation. They pointed out that these support systems support the economic goals of the port because they help boost the economy.

2.11.9 Evolution of Database Management Systems (DBMS) for Cargo Traffic

The evolution of database management systems (DBMS) is another critical factor in managing the vast amounts of data generated by heavy cargo traffic at ports like Richards Bay. DBMS has evolved from hierarchical and network systems to relational databases (RDBMS), introduced by E.F. Codd in the 1970s(Patel, Choudhary, & Patil, 2023).The 1990s saw the development of NoSQL databases to manage semi-structured and unstructured data, including GPS and sensor data, due to the need to handle large-scale data more efficiently. The port's growing data demands require transitioning to advanced database systems like NoSQL and NewSQL to handle real-time data such as truck locations, entry and exit times, and cargo weights.

2.11.10 Smart Port Technologies and Smart City Integration

Integrating smart port technologies and the broader concept of smart cities is critical for the future of port efficiency. Lehmacher et al. (2024) highlight the importance of incorporating digital technologies to manage traffic congestion, reduce environmental impact, and improve the overall quality of life in urban areas as well as near ports like Richards Bay. Digital technologies can also be used. By integrating data from various channels, such as road traffic, port operations, and logistics systems, smart port systems can synchronise truck arrivals with port tasks, reducing congestion, costs, and environmental impacts. These systems use data-driven solutions to streamline operations, enhance decision-making, and ensure a seamless flow of goods.

Decision Support Systems (DSS) are critical in this regard, offering advanced tools to improve traffic management. Integrating DSS into traffic management systems allows for more informed decision-making, improved traffic flow, and enhanced safety. As Khan et al. (2022) and Zhang & Li (2023) found, DSS can significantly reduce congestion and improve the efficiency of heavy cargo traffic. This research underscores the importance of these tools in managing the complexities of cargo transportation and ensuring the smooth operation of ports.

2.11.11 Case Study: Digital Transformation at the Port of Gothenburg

Port of Gothenburg's digital transformation incorporates advanced technologies associated with the Fourth Industrial Revolution (4IR), such as artificial intelligence, the Internet of

Things (IoT), and big data analytics, to optimise port operations. These technologies have been pivotal in improving efficiency, enhancing decision-making, reducing operational costs, and making the port a benchmark for modernising and streamlining port management globally. Gothenburg has successfully implemented a portfolio of innovative digital tools, including Big Data Analytics, the Internet of Things (IoT), and Artificial Intelligence (AI), to simplify the management of its supply chain activities. By integrating these technologies, the port has optimised coordination among stakeholders such as shipping companies, freight forwarders, and rail operators, thereby ensuring a smooth cargo flow within the port ecosystem. Notably, the implementation of an IT platform has further improved efficiency by enabling real-time data sharing across all stakeholders (Dalaklis et al., 2022).

This approach parallels the proposed solution for the Richards Bay port, where the installation of road sensors, automatic number plate recognition (ANPR) cameras, and a real-time tracking system aims to alleviate heavy cargo truck congestion. By monitoring truck movements on the N2 from Mpumalanga and the John Ross Highway and coordinating them with real-time data, the system at Richards Bay can achieve similar optimisation. The app-based truck check-in system, where drivers receive unique identifiers and real-time traffic guidance, reflects a similar vision of using digitalisation to reduce delays and ensure a steady cargo flow to the port. Gothenburg's success emphasises the importance of real-time coordination between multiple stakeholders, which is critical for ensuring Richards Bay's congestion management system achieves its objectives.

2.11.12 Comparative Analysis of Freight Data Collection Methods

The article "Compare and Contrast of Options to Collect Freight Vehicle Data in Order to Inform Traffic Management Systems" may shed light on the discussion of managing heavy truck congestion in Richards Bay using a data-focused approach, (Hargroves, K.C., et al., 2021). This article discusses the pros and cons of technologies used for gathering and monitoring data on freight vehicles. The planned system, which aims to monitor trucks in time to regulate traffic and enhance traffic flow to the Port of Richards Bay, bears consequences.

The article specifically mentions solutions such as GPS trackers and digital license plates that provide a means to monitor coal-carrying trucks on the roads. For instance, GPS tracking technology aligns with the proposed system goal of monitoring truck locations along the N2 and John Ross Highway in real time for Transnet and City traffic authorities. In certain scenarios, the precision of GPS and its ability to link GPS data with vehicle details, like driver

behavior or load weight distribution, make it a suitable choice for the task; roadside structures could incorporate this innovation to enhance the system's overall effectiveness.

2.11.13 GPS Tracking and Digital Monitoring Solutions for Traffic Management

Chunggi Lee et al. (2020) describe developing an interactive visual analytics system for analysing and forecasting traffic congestion in their article "A Visual Analytics System for Exploring, Monitoring, and Forecasting Road Traffic Congestion". The system uses vehicle detector data and incorporates a Long Short-Term Memory (LSTM) model for forecasting congestion. The system also incorporates a visual component known as Volume-Speed Rivers (VSRivers), enabling users to simultaneously monitor traffic volumes and speeds, and Propagation Arrows (Prop Arrows), which illustrate the spread of congestion across various roads. These visual tools provide insights into traffic flow patterns and enable real-time congestion surveillance and analysis citywide.

The paper, "Short-term prediction of outbound truck traffic from the exchange of information in logistics hubs: A case study for the port of Rotterdam (Nadi et al. 2022), addresses a critical aspect of traffic management: the prediction of short-term truck volumes generated by container terminals in maritime ports. Their work highlights the need for effective short-term predictions to manage truck flows, which directly impact surrounding motorways. This gap in the literature, as noted by Holguin-Veras et al. (2018) and Sarvareddy et al. (2018), focuses on the long-term generation of freight or daily truck volumes but lacks specific attention to within-day variations and the dynamics of truck flows.

The authors develop an innovative model that accurately predicts truck volumes using the Port Community System (PCS) data. The PCS enables various coordination actors (e.g., port authorities, terminal operators, carriers, and depots) to exchange operational data. This system supports traffic prediction by aligning coordination activities with truck movements. Integrating PCS data into traffic prediction models is unexplored, as most studies focus on organization optimization rather than real-time traffic prediction (Giannopoulos, 2018).

2.11.14 Data Collection Techniques in Sensor Cloud Environments

The paper titled "A Review of Data Gathering Techniques in Sensor Cloud Environments" by Ihsan Ali et al. (2020) focuses on the analysis of data collection methods in sensor cloud environments, with special attention to integrating cloud computing and wireless sensor networks (WSNs). The research points out limitations of WSN technology, including communication range and capability to manage and store data. According to the writers, these

limitations contribute to reduced network life, which can be mitigated using cloud computing as a sensor cloud approach. The merging of MWSN and WSN capabilities results in improved service quality.

From 2011 to 2020, the authors reviewed the literature and identified 43 studies on data collection in sensor cloud environments. They aimed to consolidate and streamline research in this field by highlighting the latest systems frameworks and algorithms advancements. They also employed an evidence-based approach to ensure a transparent and reproducible inclusivity process, considering the steady rise in analysis tasks in this field over the past five years.

Wireless sensor networks (WSNs) are often subject to limitations, such as a limited battery life span and the necessity of obtaining data in less time, as discussed in the article. It identifies research gaps. It also emphasises the necessity for recommendations to improve data collection in sensor cloud architecture. The researchers pointed out that existing studies fail to provide solutions for the data collection related challenges in sensor cloud systems. Such useful metrics could help direct research work to improve data management of cloud based WSNs, which is a key enabler for more efficient data-driven traffic management systems.

The authors classified the studies into three categories: system improvements, framework designs, and algorithms developed based on the presented research findings. This SLR concludes by outlining potential avenues for future research in these areas, with the aim of enhancing data collection methods, overall operational efficiency, and effectiveness. It advises improvements in areas such as secure data practices, energy efficiency, and real-time data collection. These discoveries could have significant implications for transportation control systems, including those under investigation at the Port of Richards Bay. In this scenario, it is critical for these systems to accurately gather and integrate sensor data from trucks or streets at the appropriate time.

The presented literature review underscores the significance of creating a data management system capable of handling real-time data processing and analysis, which could potentially enhance traffic management at the Richards Bay port facility. Based on the findings from this systematic literature review (SLR), which highlight the importance of collecting data frameworks, management personnel can enhance their methods for real-time traffic control, thereby promoting smoother cargo flow and reducing traffic jams.

2.11.15 Intelligent Traffic Management Systems (ITMS) for Heavy Cargo Traffic Optimisation

Chavan et al.'s, 2021 research on Intelligent Traffic Management Systems (ITMS) provides valuable insights for enhancing heavy cargo traffic management in the Richards Bay area. It is worth noting that their study also emphasises using technologies like IoT (Internet of Things), RFID (Radio Frequency Identification), and AI models to optimise traffic patterns, a strategy that resonates with the data management framework for the proposed Richards Bay data management system.

Using sensors based on the Internet of Things (IoT) could greatly improve the real-time data collection in Richards Bay by offering information on traffic flow and vehicle mobility. Chavan et al. also explores the potential of radio frequency identification (RFID) systems in giving precedence to emergency vehicles. In Richards Bay, traffic control must effectively prioritise safety and emergency response routes. By combining RFID systems with the suggested number plate recognition (ANPR) technology for Richards Bay, we could enhance effectiveness by better identifying trucks not registered in the system and organising lane priority for emergency services. Additionally, the Indian scenario suggests utilising cloud computing and real-time data processing to effectively handle the extensive data generated by the sensors and ANPR systems in Richards Bay.

In the Indian setting, RFID usage has raised concerns about the risk of tampering with RFID tags that could severely disrupt the system's functionality. This vulnerability in the Richards Bay area could be addressed by integrating RFID technology with the ANPR systems and imposing penalties for violations. This integration would establish checkpoints to verify truck registrations and monitor their movements all the way to the port.

In addition to enhancing decision-making through real-time data management and tracking systems, as previously discussed, incorporating advanced tracking algorithms further strengthens the ability of the proposed data management system to manage heavy cargo traffic effectively. For instance, the Track-by-Detection paradigm outlined by (Shuai Hua and David C. Anastasiu, 2019) offers a promising solution for tracking vehicles in real time through multi-object tracking (MOT) algorithms. This paradigm enhances accuracy in detecting and tracking moving objects, such as trucks on the N2 and John Ross Highway, which is critical to alleviating truck congestion at the Port of Richards Bay.

2.11.16 Advanced Tracking Algorithms for Real-Time Vehicle Monitoring

Advanced tracking algorithms, such as those suggested by Shuai Hua and David C. Anastasiu, (2019) have the potential to greatly improve decision-making in managing heavy cargo traffic scenarios. They are critical for timely monitoring of trucks traveling on the roads towards the Port of Richards Bay. These algorithms are pivotal in streamlining traffic movements, minimising congestion, and facilitating communication among parties. This collaboration represents a significant advancement in the management of truck movement in the area, supporting the study's goal of improving data management for traffic control.

Furthermore, this study emphasises that upgrading the Intersection over Union (IOU) method with data integration enhances the resilience of the proposed data management system by ensuring that minor variations in vehicle locations or frames do not result in tracking inaccuracies. This enhances the reliability of the tracking system, ensuring effective tracking of trucks that fail to register through the application, as detailed in the previous section. This guarantees that the system follows its rules to stop trucks from worsening congestion.

2.11.17 AI and IoT Integration in Intelligent Congestion Management Systems

Implementing a system such as the Kuala Lumpur Intelligent Congestion (KLIC) system showcases the significance of using data-driven strategies to alleviate traffic issues in areas like Kuala Lumpur (Isham, 2022). The KLIC initiative highlights incorporating Artificial Intelligence (AI) and the Internet of Things (IoT) to enhance traffic signals by adapting timings according to real-time traffic situations. This strategy reflects the advantages that could arise from introducing a system for heavy cargo truck traffic in the Richards Bay area. Real-time traffic data is employed to enhance decision-making procedures and boost the efficiency of goods transportation.

Implementing AI technology for vehicle detection, like the KLIC system in ports, involves using cameras and sensors to monitor traffic flow efficiently. Utilising sensors and ANPR cameras along routes, such as the N2 and John Ross Highway, can enhance traffic management by adjusting truck schedules in time to avoid delays and congestion effectively. For instance, the Automatic Number Plate Recognition (ANPR) cameras in the Richards Bay area can perform tasks such as monitoring trucks that have not registered through the application. This feature plays a role in minimising traffic disturbances on the roads.

Furthermore, the integration of mobile applications that offer real-time updates to road users, as exemplified in KLIC, is equally critical in the context of Richards Bay. The suggested

application for truckers allows them to check in, monitor their position in line, and receive alerts about traffic congestion, essentially imitating the KLIC systems real-time traffic updates and road situation alerts. The system notifies drivers before they start their trip, enabling them to plan effectively and minimise delays while driving.

Another feature of the KLIC system that could be quite useful is real-time traffic monitoring through video feeds. This idea could improve the effectiveness of the planned system for Richards Bay by giving Transnet and City traffic officials access to traffic updates. This makes it easier for people to work together and respond quickly to problems with traffic congestion. Using the Internet of Things (IoT) and artificial intelligence (AI) to find traffic congestion in the KL International Airport Corporations (KLIC) project is also in line with the goal of improving the port's ability to make decisions by putting in place a data management system that gives information on truck volumes, delays, and operational capacity.

2.11.18 Data Fusion Techniques for Enhanced Traffic Flow Monitoring

Integrating data fusion methods into intelligent transportation systems (ITS) significantly improves the effectiveness and productivity of managing traffic flow in handling heavy cargo traffic at ports, such as Richards Bay Port, seamlessly. Real-time data fusion methods enable the collection, processing, and analysis of traffic parameters from sensor devices, like GPS trackers, cameras, radars, and loop detectors.

In their study on data fusion techniques for time and multi-sensor traffic monitoring (Kashinath et al., 2021), the authors emphasised the importance of integrating different traffic sensing methods to significantly enhance the accuracy of traffic condition assessments. They highlighted how combining data from sources such as vehicle volume and speed can improve congestion predictions and help optimise traffic flow on roadways. Truck traffic jams have been a concern in the Richards Bay area. A proposed system for managing real-time information could use fusion methods to combine inputs from sensors like ANPR cameras, road sensors, and GPS details. This approach in the case of Richards Bay port would aim to enhance forecast accuracy and decision-making for entities like Transnet, RBCT, and the City of uMhlathuze traffic departments (as mentioned by Kashinath et al., 2021).

2.11.19 Role of Multisensory Detection in Traffic Control

Multisensory detection plays a role in traffic control, as underscored by Kashinath et al. (2021), a study that stresses the necessity of employing sensors for precise traffic assessment purposes. The results of combining traffic data could enhance the efficiency of traffic control at Richards

Bay port. This could be achieved by utilising data sources in real-time and employing advanced fusion methods to predict problems, streamline truck movements, reduce congestion, and enhance operational effectiveness at the port.

The concept of Data Fabric presents a valuable framework. Data Fabric technology enables the seamless integration of diverse data sources by implementing a unified architecture that gathers, stores, and processes data from multiple platforms, such as cloud-based systems, local databases, and external sensors, for optimal decision-making. This real-time integration aligns well with the proposed data management system for tracking heavy cargo trucks.

The data fabric model uses a knowledge graph that maps out relationships between entities and concepts in a particular business domain. Richards Bay's traffic data management system could include entities like trucks, routes, traffic sensors, and even stakeholders like the City of uMhlathuze, Transnet, and Richards Bay Coal Terminal (RBCT). By automating the association of new data sources with these entities, Data Fabric allows for swift adaptation to evolving traffic patterns, ensuring that traffic congestion insights are timely and accurate.

Moreover, Data Fabric's flexibility in supporting cloud-based infrastructure, as demonstrated by platforms like IBM Cloud Pak for Data and Azure Synapse Analytics, ensures the system can scale to accommodate increasing data volumes as Richards Bay's cargo traffic grows. With features such as data orchestration, multi-source integration, and real-time analytics, this technology ensures continuous and efficient management of truck data. It also supports cross-stakeholder collaboration by providing all parties, including Transnet and the City of uMhlathuze, with up-to-date information on truck arrivals, road congestion, and cargo movements.

2.11.20 Cloud-Based Infrastructure for Traffic Data Scalability

In the context of enhancing traffic management in Richards Bay, this unified architecture for managing big data brings end-to-end integration to key stakeholders, ensuring that real-time data sharing is possible across all traffic management entities (Kuftinova et al., 2022). This aligns with the research questions on how a data management system can improve decision-making through efficient data collection, storage, and analysis between key stakeholders.

Integrating technology in road transportation systems offers the potential to enhance safety measures and streamline traffic control for the efficient movement of heavy goods vehicles in key ports like Richards Bay. As previously mentioned, a structured data management system can significantly enhance truck traffic control. This critical element aligns seamlessly with the

broader technological advancements in smart infrastructure and IoT-powered transportation networks.

2.11.21 Smart Highways and ANPR Systems for Congestion Reduction

Technology and interconnected vehicle systems empower smart highways, offering enhanced monitoring features that can alleviate traffic congestion on roads leading to the Port of Richards Bay. A potential data collection system that combines road sensors with ANPR cameras could effectively complement these advancements. In road projects, like V2V (vehicle-to-vehicle communication) and V21 (vehicle-to-infrastructure communication), vehicles and infrastructure can communicate instantly to improve decision-making for traffic authorities (IoT Magazine, 2018). These innovations can help prevent traffic jams by providing real-time traffic updates, alerting authorities and drivers about risks or delays, and efficiently managing truck flow into ports.

In addition, as previously mentioned, real-time traffic surveillance systems are being implemented in regions such as Atlanta Georgia. These systems highlight how powered traffic cameras and intelligent traffic signals can adapt signals in time to enhance traffic flow. Richards Bay could also implement these advancements by combining sensors and cameras with a data management system to avoid traffic congestion caused by the movements of coal trucks (IoT Magazine 2018).

Building on prior discussions, Lau et al.'s research in 2022, which introduced a PC-based intelligent traffic monitoring system in populated urban areas like uMhlathuze, underscores the critical need for real-time analysis, particularly in the Port of Richards Bay area. The Hong Kong-established innovative system, capable of instantly identifying various vehicle types and license plates, significantly enhances the movement of large cargo trucks in Richards Bay. The ability to respond instantly can significantly aid in managing the increasing strain on our infrastructure, particularly critical for locations and ports grappling with issues arising from their expanding cargo capacity.

2.11.22 Intelligent Traffic Monitoring System and GoPro Cameras

The research discusses a computer-based system that doesn't require investment. This could be beneficial for infrastructure in Richards Bay, where financial constraints or logistical challenges may hinder the effective implementation of systems. (Lau et al.'s, 2022) description of a traffic monitoring system that uses GoPro cameras for data collection suggests that the N2 highway and John Ross Highway in Richards Bay could also benefit from this approach. The

research project will integrate this technology with the data management system. Congestion can be reduced by identifying bottlenecks and efficiently managing heavy vehicle queues in congested areas such as roads or highways. The Hong Kong study's use of an object detection model that depends on learning methods like the Single Shot Multibox Detector (SSD) and MobileNet proves to be an approach for accurately and swiftly identifying vehicles. Utilising this technology in Richards Bay's traffic control system could enhance the precision of truck identification and optimise decision-making processes. It could also facilitate communication among stakeholders such as Transnet and the traffic authorities of the City of uMhlathuze.

By incorporating these findings from Lau et al.'s (2022) research into the data management system at Richards Bay port, the City can enjoy improved traffic monitoring solutions that streamline cargo flow and reduce congestion while also aiding decision-making for everyone involved in the operations. The innovative technologies showcased in the study conducted in Hong Kong serve as a guide for developing a traffic management strategy tailored to tackle the specific issues posed by heavy truck traffic at Richards Bay Port.

2.11.23 Data Security and Safe City's Secure Traffic Management Architecture

Integrating insights from Zhang et al.'s (2020) Safe City architecture contributes significantly to the discussion of traffic management and data management at the Richards Bay port, particularly concerning data security and real-time analytics for truck congestion. Given the complexity and volume of data generated by sensors in smart cities, Safe City's emphasis on a secure, multi-layer data management framework is highly relevant. Safe City's architecture, with its distinct data security, computation, and decision-making layers, offers a potential model for developing secure data management protocols for Richards Bay's traffic system.

Applying payload based symmetric encryption for truck data on the N2 and John Ross Highway could prevent the unauthorised access and manipulation of real-time traffic data. Since truck check-ins and live congestion reports involve sensitive operational data, incorporating robust security measures ensures data integrity and operational reliability. This approach aligns with the need for secure data transmission in IoT-enabled environments, where vulnerabilities can lead to traffic mismanagement or unauthorised interception, as highlighted in the SafeCity study (Zhang et al., 2020).

Further, SafeCity's customised Hadoop framework for secure and efficient data storage provides an adaptable model for optimising Richard Bay's data management capacity. Using a customised Hadoop distributed file system (HDFS) and dynamic YARN scheduling, as

SafeCity suggests, the Richards Bay traffic data management system could improve data processing speed and minimise storage costs. This setup would efficiently manage the data influx from ANPR cameras, sensors, and app check-ins, supporting the large-scale data needs of Richards Bay's daily truck monitoring and enhancing response times for congestion alerts. Richards Bay port could thus adapt Safe City's layered architecture to provide robust, real-time decision support for managing truck traffic, while maintaining high security and storage efficiency.

Furthermore, FMSs Data Fusion and Visualisation Platform gathers data from sources to support informed decision-making processes. In the case of Richards Bay, combining sensor data, check-in records, and ANPR camera footage on a platform would enable stakeholders, like Transnet and uMhlathuze, to have a centralised perspective on truck activities. The dashboards of an established system, such as the one from a company named FMS, resemble this combined perspective. It can function as a tool to help with decision-making by making it easier to understand real-time data interpretations and predictions on traffic congestion and truck volumes.

By using these platforms, FMS also tackles an issue in data fusion: combining data from various sources to create a comprehensive model necessary for establishing an effective truck monitoring system in Richards Bay. This integrated model addresses challenges related to managing data from sources, like merging information from devices and user inputs, and proves valuable in dealing with the congestion of trucks in Richards Bay.

2.12 Research Gap

Existing literature has offered various insights into optimising cargo transportation through advanced technologies such as intelligent decision support systems (IDSS) and big data analytics. However, most of these studies have not specifically addressed the application of this data management integration to heavy cargo traffic in ports, resulting in a research gap. For instance, Bolodurina and Speshilov's (2023) study showed that small firms can implement effective cargo flow management through IDSS, but it did not specifically address the challenges associated with heavy cargo traffic in ports. In a comparable manner, Chen et al. (2021) and Shmatko, Barykin, Sergeev, and Thirakulwanich (2021) also explored solutions for distribution organisation centers that are vehicle-based but did not emphasise appropriate data-driven decision-making processes for ports that are facing challenges with high cargo volumes and complex traffic situations.

Therefore, it can be concluded that the impact of these technologies on large cargo ports has received limited research attention. Likewise, limited knowledge exists about how non-technological factors like stakeholder coordination and constraints resulting from poor infrastructure impact the optimisation of port traffic management. This research aims to fill this gap by investigating how technological advancements, in combination with collaborative efforts from appropriate stakeholders, can effectively improve heavy cargo traffic decision-making, especially at the Port of Richards Bay, to enhance smooth operational efficiency in this port and improve its economic performance.

2.13 Proposed Intervention for Optimising heavy cargo traffic management

In addressing the challenges of heavy cargo traffic management at the Port of Richards Bay, the proposed interventions must incorporate several critical elements for the successful implementation and acceptance of real-time data management system and traffic control technologies. These elements will include a combination of advanced technological solutions, stakeholder engagement, and infrastructural improvements, all aimed at easing the heavy cargo traffic and enhancing decision-making processes in the port area.

First, inspired by the work of Nadi et al. (2023) in predicting truck volumes using real-time data from logistics hubs like the Port of Rotterdam, the development of a real-time data visualisation system tailored to the specific needs of Richards Bay is proposed. This system will incorporate sensors, automatic number plate recognition (ANPR) cameras, and a mobile application to track and manage heavy trucks travelling on the N2 and John Ross Highway toward the port. Such a system will enhance truck flow by providing real-time data on traffic conditions, queuing positions, and port capacity, allowing for better traffic management and minimising congestion. The success of these real-time systems in managing traffic volumes at ports, as shown by Nadi et al. (2023), reinforces the need for similar interventions in Richards Bay, where truck traffic management is critical.

To complement the technology, stakeholder engagement is essential, as collaboration between logistics operators, truck drivers, and port authorities plays a significant role in the smooth functioning of traffic management systems (Heilig and Vob, 2017). Training programs will be initiated to educate users on the functionalities of the real-time tracking system. This approach aims to foster acceptance of the technology, ensuring that drivers and logistics operators understand how to interact with the system, thereby improving compliance and system efficiency.

By incorporating user feedback and focusing on ease of use, the system can be better aligned with the daily operational needs of all stakeholders.

Additionally, financial and infrastructural support will be critical for the success of this intervention. Drawing insights from studies, it is recognised that building robust digital infrastructure, including advanced ANPR cameras and IoT-enabled sensors along the roadways leading to the port, is critical. This infrastructure will not only support real-time data collection but also enhance the system's ability to predict and manage truck volumes. Partnerships between government entities, port authorities, and private logistics companies will be pursued to mitigate the financial burden, ensuring shared investment in the required technology. Additionally, subsidies for technology adoption and system maintenance will be explored to ensure the long-term sustainability of the intervention.

Finally, ensuring the system is user-friendly and accessible across various devices is a critical consideration. The mobile application component of the system will be designed to be intuitive and compatible with a range of devices, ensuring that truck drivers can easily check in, receive real-time notifications, and track their queue status. Support services, such as a helpdesk or online resources, will be made available to assist users with any technical difficulties, thus increasing user confidence and system reliability.

In summary, the proposed intervention for the Port of Richards Bay focuses on the integration of advanced real-time data management technologies, the involvement of key stakeholders, and the development of necessary infrastructure. This multi-faceted approach will enable the port to better manage heavy cargo traffic, reducing congestion and enhancing decision-making processes. By learning from the successes of similar interventions in other ports, such as Rotterdam, and adapting them to the specific needs of Richards Bay, a sustainable solution for the port's traffic management challenges is aimed to be created.

The suggested approach to improving the management of heavy cargo traffic at the Port of Richards Bay focuses on establishing a data management system as a base for real-time data visualization and the coordination of trucks on key routes leading to the port. Namely the N2 and John Ross Highway. During the initial stages of development, data management and timely tracking are prioritised. However, the system is being designed with growth in mind, incorporating cutting-edge technologies as the project progresses.

2.13.1 Exploring the Core of Data Management System.

The main goal is to create a system for managing data in real-time that uses sensors and ANPR cameras along with an app to keep track of truck activities and traffic situations at the port efficiently. Taking inspiration from research by Nadi et al. (2021), which showcases how real-time information can help alleviate congestion at ports like Rotterdam, the system aims to collect and display up-to-the-minute details on queue locations, traffic statuses, and port capacities. This method will assist the traffic management team and port authorities in Richards Bay to enhance traffic movement and reduce congestion.

2.13.2 Potential Growth Opportunities, for Data Analysis and AI Incorporation, in the Future

Currently, the primary goal is to set up the functions for managing data; however, the system architecture is also being planned to easily incorporate future enhancements. By focusing on establishing a framework for gathering and visualising real-time information, it is envisioned that the system will be expanded to incorporate analytics and predictive modelling. Na Li et al.'s 2022 research, which highlighted the benefits of using analytics to predict truck arrivals and control traffic flow, inspires this strategy. Once Richards Bay has a foundational system, integrating features could aid in effectively anticipating peak traffic periods and proactively regulating vehicle flow.

Furthermore, as intelligence and machine learning technologies advance, they can enhance systems to provide deep insights into traffic patterns, opening opportunities for real-time data-driven decision-making. For example, by utilising machine learning algorithms to assess current data trends related to truck traffic, it becomes feasible to anticipate and address congestion issues before they worsen significantly. In the future, the data management system can handle automated interventions by using AI notifications and dynamic queue management, which adjusts to changing road conditions.

2.13.3 Creating a Strategy for the Integration of IoT and Infrastructure

According to research by Linlin You et al. (2021), which focuses on mobility sensing technologies, the live data system will have the flexibility to expand to include Internet of Things (IoT) sensors on the roads leading towards the port. While the initial rollout may only involve ANPR cameras and necessary sensors, the system setup will enable the integration of additional devices as resources and needs grow. This flexible method guarantees that the

system can develop into a network of sensors that can consistently monitor truck activities, traffic congestion levels, and road conditions.

2.13.4 Involving stakeholders. Ensuring accessibility, for users.

Building partnerships with stakeholders is critical throughout the process. The process begins with the establishment of data management systems and continues with the planning of future advancements. Ensuring communication with port authorities and other relevant parties is key to tailoring system improvements to their requirements. In this phase, a user-friendly mobile app will be rolled out to initiate the process smoothly and efficiently. It will offer real-time alerts and check-in capabilities. This could potentially grow to include advanced functionalities like predictive analysis and automated guidance down the line.

2.14 Conclusion

In summary, the planned initiative in Richards Bay will begin with establishing a data management system that aims to alleviate heavy cargo traffic congestion through real-time monitoring and visualisation. However, the design of this system will allow for growth. It will facilitate the inclusion of data analytics, predictive modelling, AI, and IoT. By establishing a framework, the Port of Richards Bay is ensured to be prepared for future advancements, enabling the adoption of state of the art technologies and providing a sustainable and effective solution for traffic control.

Chapter Three: Research Methodology

3.1 Introduction

Research methodology is defined as the set of procedures or guidelines used to conduct a specific research study in alignment with the underlying ideas, beliefs, and values that shape that approach (Somekh et al., 2005, p. 346). This section delineates the research methods employed to investigate the potential of data management systems in mitigating the congestion resulting from heavy cargo traffic at the Port of Richards Bay. The research involved a literature review following the PRISMA framework to ensure a replicable analysis of existing studies focusing on data-driven strategies for traffic management solutions. A qualitative approach was adopted that centred on data analysis to explore effective traffic management solutions using data insights. This method utilises resources, such as papers, industry analyses, and official documents from relevant parties, to thoroughly understand the traffic management obstacles and potential benefits arising from data merging. Thematic analysis was used to synthesise the findings.

The chapter is organised to cover the research design, rationale, research paradigm, target population, sampling method, eligibility criteria, and data sources. These sections detail the conduct of the systematic review and explain the rationale behind key methodological decisions. This methodology enabled an in-depth analysis of current data management and traffic control frameworks, supporting the study's objectives of identifying effective strategies for optimising cargo traffic flow and informing real-time decision-making at the Port of Richards Bay.

3.2 Research Design

The research used a systematic review approach based on the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta Analyses) (Salameh, 2020) as illustrated in Figure 3 this method was selected to ensure a transparent and easily replicable examination of existing literature. The systematic review was tailored to concentrate on data management and traffic control solutions, aiming to explore the strategies and perspectives of stakeholders in improving heavy cargo traffic flow at the Port of Richards Bay.

The structured review approach, in conjunction with PRISMA, thoroughly examines data thoroughly and comprehensively (Snyder, 2019). This approach facilitated applying the exploratory research design in the literature review, ensuring that the collected data is relevant, credible, and sufficient to address the research questions.

To address the challenge of heavy cargo traffic congestion at the Port of Richards Bay, this study conducted a systematic review of secondary data. The desktop study method made it possible to look at a lot of secondary data sources that were already out there on topics like traffic congestion, decision-support tools (DST), and data management systems in smart city and logistics settings. The qualitative nature of the study was suitable for gaining in-depth insights into traffic management challenges and possible solutions without direct data collection from stakeholders.

This qualitative, systematic review approach alleviates issues by utilising accessible data and paving the way to analyse available literature. Therefore, the researcher consolidated and analysed publicly available secondary data, policies, and reports instead of gathering new data. The study established a framework based on evidence, incorporating data from diverse sources like Transnet, RBCT, and the City of uMhlathuze, as well as international examples. The approach the study used proved to be budget-friendly and timesaving because credible information exists, and while comparing industry standards, it is not necessary to gather new data first-hand.

3.2.1 Rationale of the Research Design

Undertaking a systematic review, supported by PRISMA, is critical in this situation for various reasons. Firstly, it allows the research team to thoroughly examine studies and evaluate various aspects of data management and decision-making tools associated with traffic management. Moreover, the systematic review is well suited for identifying trends, patterns, and valuable insights on decision support tools (DSTs) as data systems from various knowledge sources. The thorough instructions of PRISMA ensured clarity in selecting literature, enabling upcoming researchers to replicate or enhance the research work of their predecessors. PRISMA improves the reliability of results and reduces bias during the review process (Salameh, 2020).

In addition to enhancing reliability through PRISMA, steps were taken to ensure the validity and reliability of the overall research process. For validity, the inclusion and exclusion criteria for literature selection were clearly defined to ensure that only relevant and credible sources were used. Triangulation was achieved by consulting a wide range of sources, including academic articles, policy documents, and technical reports, to support findings and interpretations. Reliability was further strengthened by applying a consistent review framework and documenting the decision-making process throughout the study. This transparent

methodology allows for reproducibility and strengthens the trustworthiness of the research outcomes.

The desktop research design was selected to enable extensive exploration of secondary data, free from the logistical constraints of primary data collection. The abundance of information pertaining to the management of heavy cargo traffic at the ports also inspired the decision to opt for a desktop study-based research method. The complexity of the subject and the presence of documents such as reports, policies, and articles made it well-suited for a desktop study. Moreover, this approach guaranteed that the study stays centred on cost strategies for managing data while integrating standards of excellence.

The unique nature of the research issue at hand further supported the choice to use qualitative research in this study. Delving into complex processes and stakeholder viewpoints that impact the management of heavy cargo traffic at the Port of Richards Bay was critical. The study employed qualitative research to explore the potential for integrating and utilising data management systems while illuminating the obstacles and benefits stemming from stakeholder interactions.

3.3 Research Paradigm

This study aligned with an interpretive paradigm, as it seeks to interpret and understand the underlying patterns and meanings within existing literature and secondary data on traffic management and data integration. Using a qualitative approach, the study aims to explore the perspectives and findings of existing research to understand the challenges of truck congestion and the potential of data-driven solutions at the Richards Bay port. The interpretive paradigm helps to put together a lot of complicated, interconnected factors that affect the management of heavy cargo traffic. These include inefficient logistics, communication problems, and stakeholders' needs for real-time data.

This study employed an interpretive philosophy to explore how individuals and groups interpret their social environment, specifically focusing on stakeholders' perceptions of data use (Busetto, Wick & Gumbinger, 2020). Context is critical within interpretivism, highlighting that context shapes human behaviour and decision-making (Chai et al., 2021). By analysing documents and reports, the study aimed to uncover the underlying viewpoints that shape human behaviour and shed light on the obstacles and possibilities linked to managing cargo traffic and data systems. This paradigm is particularly suitable for desktop research, where the goal is to

interpret existing qualitative data, such as policies, reports, and strategic plans to reveal insights into cargo traffic management challenges.

While the interpretive philosophy enabled an in-depth understanding of Stakeholders' experiences and perceptions regarding traffic congestion at the Port of Richards Bay, it may limit the generalizability of the findings. Furthermore, the subjective nature of data interpretation and the potential for researcher bias present challenges to reliability. Nonetheless, the approach was appropriate given the exploratory aim and the need to uncover contextual insights.

3.4 Target Population and Sample

3.4.1 Target Population

The population for this desktop study consists of existing literature, industry reports, and government publications relevant to traffic congestion, heavy cargo logistics, and data management in port and urban environments. Using the PRISMA method, the study employed systematic sampling by identifying and screening research articles, reports, and case studies published within the past 7 years (2018-2024) that are pertinent to the Port of Richards Bay and similar contexts in traffic management (Salameh, 2020).

In this desktop study, the "population" consisted of publicly available documents, reports, and studies from relevant stakeholders such as Transnet, RBCT, the city of uMhlathuze Municipality, and others who have addressed or are affected by heavy cargo traffic congestion at the port of Richards Bay.

3.4.2 Sampling Method

In the context of this desktop-based qualitative study using a systematic literature review, the sample size refers to the number of textual sources reviewed rather than human participants. A total of 55 eligible sources were included after a rigorous screening process aligned with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. These sources included peer-reviewed journal articles, institutional reports, government documents, and case studies relevant to data management systems, traffic congestion solutions, and decision-support technologies in port and urban logistics environments, with a specific focus on heavy cargo management in contexts similar to the Port of Richards Bay.

Sampling in this desktop study was conducted through the purposeful selection of relevant documents from electronic databases, notably Google Scholar and the University of KwaZulu-Natal (UKZN) Library portal. Search strings used to identify pertinent literature included:

"data management in transportation logistics"

"heavy cargo truck congestion at South African ports"

"decision support systems AND Richards Bay"

"intelligent traffic management systems AND freight transport"

"data-driven solutions for port congestion"

Boolean operators such as AND, OR, and NOT were applied to refine the search results. Filters were used to limit results to peer-reviewed publications between 2018 and 2024, written in English, and relevant to African or comparable international port contexts. To analyse the qualitative data gathered from these 55 sources, the study employed a thematic analysis approach, guided by Braun and Clarke's (2006) six-phase method: (1) familiarisation with the data, (2) generation of initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the final report. The data was managed and coded manually using Excel and NVivo software tools to ensure systematic categorisation.

Additionally, framework analysis was employed to map findings against the study's predefined objectives and research questions. This matrix-based method, as described by Gale et al. (2013), allowed the researcher to chart key information into thematic categories such as technology adoption, real-time data application, stakeholder collaboration, and traffic optimisation tools. These categories provided a structured lens through which the literature could be analysed, interpreted, and aligned with the overall aim of improving traffic management at the Port of Richards Bay through integrated data systems. By triangulating data from diverse authoritative sources, including Transnet, Richards Bay Coal Terminal (RBCT), and City of uMhlathuze Municipality reports, this study ensured robust thematic saturation and contextual depth. This methodological rigor supports the credibility and transferability of the study's findings and recommendations.

3.4.3 Sample Size

Given the desktop nature of this study, there is no specific sample size for secondary sources, but the emphasis was on the quality and relevance of documents. The study's objective was to scrutinise documents relevant to heavy cargo traffic management, data management systems, and operations at Port Richards Bay. Sources were selected until data saturation was reached, at which point no new substantial information or insights emerged from additional documents

(Mason, 2010). The PRISMA framework facilitated systematic identification, screening, and inclusion of literature according to predefined eligibility criteria.

3.5 Data Collection Methods

Since this study was a desktop study, data collection consisted of collecting and reviewing relevant secondary sources. The PRISMA method was chosen to structure the literature review process, offering a systematic approach to identifying, screening, and synthesising sources. The following steps were followed:

Identification: Keywords related to "traffic congestion," "data management systems," "decision support tools," "heavy cargo traffic," and "Port of Richards Bay" were used to locate sources in academic databases, journals, and industry reports.

After initial identification, Sources were screened based on their relevance to the study's research questions and objectives, with a particular focus on data integration for traffic management.

Eligibility: Eligible sources were reviewed for content quality and relevance to ensure they provided empirical insights or data pertinent to the Port of Richards Bay or similar logistics environments.

Sources that met all criteria for a detailed review and analysis were included.

The chosen PRISMA method involved identifying the following elements.

- The Port of Richards Bay has documents that outline policies and strategies for managing heavy cargo traffic.
- Research and practical instances that delve into the application of decision support and data management systems in the realm of heavy cargo traffic management are being examined.
- News articles and official government reports explored the current state and emerging trends in the logistics sector in Richards Bay, South Africa, and globally.

This selection process is visually represented in the PRISMA flow diagram (Figure 3), which outlines the number of sources at each stage, identification, screening, eligibility, and inclusion, highlighting the transparent and structured nature of the review process. The relevant documents were systematically reviewed to understand the current state of heavy cargo traffic management, particularly regarding truck congestion in Richards Bay. Key documents

included past research studies, government reports, and operational data publicly available from Transnet, RBCT, and the City of uMhlathuze Municipality. The data collection centred on grasping the issues related to managing heavy cargo traffic and the significance of decision support systems, as well as exploring ways to enhance data management practices to improve operations efficiency and effectiveness.

3.6 Data Analysis

Data analysis transforms the collected raw data into meaningful facts and ideas for either qualitative or quantitative understanding. And as Kothari (2004, p.134) noted in the analysis of data is deconstructing the whole into parts, examining the parts, and then reassembling or reconstituting the parts in a new or modified form. A qualitative synthesis approach to the analysis of data was undertaken as applicable to drawing out themes, trends, and analytical insights from the secondary sources that were reviewed within the study.

For the purpose of this analysis, a respondent was defined as one source (article, report or document) covering heavy cargo traffic management (inclusive of port management) in the Port of Richards Bay. The analysis was thematic and sources focused on the different aspects of managing heavy cargo traffic were thematically coded. Several themes related to the objectives of the study emerged, such as data management, decision systems, traffic congestion measures, multi-actor communication and coordination. Thematic analysis was conducted within the included studies to explore similarities and Differences for traffic management practices, with a key focus on how ports deploy data technologies to improve operations and reduce congestion.

Manual coding was performed, and a structured coding framework was developed based on Braun and Clarke's (2006) six-phased model for thematic analysis. This process included reviewing the qualitative supermatrix and coding themes, resulting in 21 abstract categories that formed the basis for the final synthesis. The findings were grouped into sub-themes using the coding framework, which identified real-time vehicle monitoring, sensor-based data collection, governance and enforcement, and system interoperability. These categories were used to describe cross-study findings and to generate best practice guidelines applicable to the Richards Bay context.

The PRISMA approach was utilized to guarantee strictness and transparency in the selection and analysis of the literature. The process of literature review is illustrated by PRISMA flow chart (Figure 3) and followed a structured and stepwise approach (identification, screening,

eligibility, inclusion) ending up with 55 relevant studies for critical read. When we talk about the above certain studies, they were not used separately, but together for an integrated analysis between them, toward comparative analysis results among the port logistic and ITS systems.

Finally, these qualitative findings have informed the adaptation of context-specific guidelines for the implementation of data-driven traffic control and decision-support systems at the Port of Richards Bay. The deliberate use of analysis led to a better understanding of gaps in regulation of cargo traffic and the potential of technology to foster coordination for greater efficiency, safety, and intelligence.

3.6.1 Thematic analysis

A systematic literature review was conducted using the PRISMA method in qualitative research to support the thematic analysis technique, which gathered information from the documents and identified common themes within the dataset. The Miler (2021) and Kiger and Varpio (2020) methodologies form the basis of these steps, which can apply in a variety of scenarios by following this six-step process:

- Familiarising oneself with the gathered materials involves reading them to understand the content and initial trends concerning traffic control and congestion problems.
- Coding: Creating code at the beginning helps to bring out themes or patterns found in the data that are relevant to the study's objectives.
- Theme Development: Developing themes involves organising codes into categories, like "patterns of traffic congestion, "technology gaps, and "data-driven decision-making".
- Reviewing Themes: Ensuring that the themes align with the topics discussed in all documents and with the study's questions and objectives.
- Defining and Naming Themes: Refining the themes to accurately capture their core meaning before finalizing them.
- Writing Reports: Compiling the results into an organised report that reflects the research goals and backs up conclusions with evidence found in the reviewed documents.

This methodical approach to conducting a thematic analysis guarantees not only a thorough examination of the data but also a comprehensive understanding that aligns with the study objectives.

3.7 Ethical Considerations

The key ethical considerations include avoiding plagiarism through proper citation, ensuring data integrity by using valid documents, maintaining transparency in documentation, and handling confidential information carefully to protect any sensitive details. By observing these principles, the research aligns with the ethical standards necessary for trustworthy and responsible research outcomes (Alem, 2020).

Since this is a desktop study that uses secondary data, the primary ethical considerations involve maintaining the integrity of the research process.

- Plagiarism: All sources of information have been properly cited and referenced.
- Data integrity: The study ensured data integrity by using valid documents.
- Transparency: Clarity and transparency are maintained by recording each stage of the research process, from data collection to analysis, with these measures implemented using PRISMA.
- Confidentiality: Although personal information was not used in this study, some documents might have included data that was treated with confidentiality and solely utilised for the designated research objective.

  Ethical Clearance: The attached letter of ethical clearance confirms the academic leader's exemption status for the study.

3.8 Trustworthiness of the Study

According to Amin et al. (2020), qualitative research will ensure credibility, dependability, transferability, and confirmability in the following ways:

- Credibility: Credibility was achieved by selecting quality and reliable sources using the established PRISMA method (Amin et al., 2020; Rose & Johnson, 2020). To ensure the inclusion of only relevant and trustworthy sources, quality was determined based on peer-reviewed status, publication in reputable academic journals or official institutional reports, clarity of methodology, empirical grounding, and direct relevance to the study's focus on data management and traffic optimisation.
- Transferability: Detailed descriptions of the research context enable the application of the findings to similar cases (Adler, 2022).
- Dependability: Systematic documentation of every step of qualitative inquiry is critical for ensuring the consistency of various research activities over time (Aref et al., 2021).

An audit trail was maintained throughout the research process to document key elements such as the selection criteria, document review procedures, data extraction steps, and the development of thematic codes and categories. This process ensured transparency, reproducibility, and methodological rigour.

- Confirmability: To minimise potential distortion and ensure robust findings supported by multiple sources of evidence, the researcher regularly reflects on biases during data analysis (Aref et al., 2021; Rose & Johnson, 2020). Data triangulation was achieved by drawing on a diverse range of documents, including government reports, peer-reviewed academic studies, and industry publications, which provided multiple perspectives and enhanced the credibility and depth of the analysis.

3.9 Limitations and Delimitations of the Study

3.9.1 Limitations

The study relied on qualitative data from secondary sources rather than primary data collection, which may limit the depth of insights, as the available data might not comprehensively address all aspects of the research problem. Additionally, accessing relevant documents posed a challenge, as some pertinent data was not publicly available in the databases. The absence of interviews or direct interactions with stakeholders, like Transnet officials or traffic officers, could potentially lead to the loss of potentially valuable data. Although the PRISMA method helped standardise the literature selection process, it required considerable time for searching, screening, and analysing documents, which proved challenging within the study's timeframe.

3.9.2 Delimitations

The study could potentially be delimited as follows: The study focused geographically on heavy cargo traffic management and congestion specific to the Port of Richards Bay. Purposive sampling was used for document selection, identifying relevant secondary data sources through the PRISMA method, and only documents that met the eligibility criteria were included to maintain focus. The research methodology exclusively adopted a desktop study approach with a systematic literature review (PRISMA) and employed qualitative methods, focusing on an in-depth understanding of the available literature.

3.10 Conclusion

This chapter details the research methods used to investigate data-driven approaches for managing heavy cargo congestion at the Port of Richards Bay. The study conducted a review using the PRISMA framework to systematically analyse current literature and secondary data regarding data management systems and traffic control strategies. Critical choices were made, such as selecting the interpretivist paradigm and using a desktop research design in conjunction with analysis, to ensure a cost-effective topic exploration.

By combining information from reports, academic studies, and established policies in this approach, exploring existing issues and remedies concerning heavy cargo traffic control and data integration was facilitated. The structured and replicable approach adopted here supports the study's aim to explore the use of data management to optimise and reduce heavy cargo traffic at the port of Richards Bay. The subsequent chapters further explore and discuss data insights and practical solutions for optimising heavy cargo management at the Port of Richards Bay, building on the findings from this systematic review.

Chapter Four: Presentation of Findings, Interpretation and Discussions

4.1 Introduction

The main goal of this chapter is to showcase and explain the research results on managing heavy cargo traffic and how data systems can help alleviate congestion at the Port of Richards Bay. The chapter examines traffic data trends, digging into congestion patterns, and grasping infrastructure enhancements to tackle the study goals and research questions.

The following research questions structure the study's results: What are the current traffic data congestion points, high-impact points, trends, and patterns, particularly on the N2 and the John Ross Highway, leading to the Port of Richards Bay? Is it feasible to use a developed data management system to optimise heavy freight traffic flow and lessen the strain on local infrastructure and the environment? What are the recommended strategies for developing a system that integrates real-time data collection, visualisation, and communication tools for stakeholders such as the Richards Bay Coal Terminal (RBCT), Transnet, and City of uMhlathuze traffic authorities?

These improvements are discussed below in the context of how a suggested data management system could support and enhance traffic management toward and at the Port of Richards Bay. Improvements such as the expansion of Transnet's truck staging area and the ongoing construction of the Eyamakhosi truck stop along the John Ross Highway are contributing to the reduction of truck congestion overall.

4.2 Presentation of Findings

4.2.1 Analysis of heavy cargo traffic patterns and high-impact zones

The study examined traffic jam data specifically observed along the N2 and John Ross Highway routes, which are critical for transporting coal to the port by truck. The findings highlighted peak traffic congestion at times of the day when there is a backlog of vehicles due to disruptions in the railway system. These critical areas of impact and peak congestion times emphasize the necessity of using data-driven scheduling and real-time monitoring to regulate truck traffic and facilitate the flow of vehicles, as their status negatively impacts the city's infrastructure.

4.2.2 Data Management's Role in Decision-Making – Feasibility

Data management is critical for making informed decisions to improve traffic efficiency of heavy cargo. By monitoring and studying truck movements closely through a data management system, stakeholders receive updates on areas and traffic trends, empowering them to make strategic choices based on accurate information. This supports the study's goal of exploring the feasibility of utilising data management to enhance traffic flow by showcasing its effectiveness in minimising congestion and enhancing resource allocation, including optimising the deployment of traffic officers and scheduling unloading activities at the Port of Richards Bay.

4.2.3 Development of a Real-Time Data Management System

A theoretical framework for a data management system was created to facilitate monitoring and decision-making assistance after analysing the results of this subject matter study. This system incorporates sensors monitoring, Automatic Number Plate Recognition (ANPR) cameras, and a check-in application designed for truck drivers. By examining real-time information regarding truck locations and traffic congestion levels, relevant individuals can adjust truck travel plans as needed. The data system facilitates communication among stakeholders, expediting the process and ensuring the dispatch of trucks only when unloading space is available. This approach helps to avoid traffic jams and long waits along the roads.

4.2.4 Collaborative Framework with Key Stakeholders

A partnership between Transnet, the City of uMhlathuze, and the Richards Bay Coal Terminal (RBCT) was considered critical for a successful traffic management system. Transnet's current progress in expanding truck staging areas and constructing the Eyamakhosi truck stop is a testament to this teamwork approach. The new facilities offer staging areas; however, an efficient data management system is required to organise truck movements and deliver instant updates to everyone involved. This collaboration is anticipated to enhance traffic flow, improve scheduling predictability, and alleviate road congestion.

4.3 Interpretation and Discussions

4.3.1 Real-Time Data and Improved Decision-Making

Analysing traffic information and recognising congestion patterns reveal the importance of a data tool that enables stakeholders to make decisions based on present circumstances rather than just depending on past data or fixed timetables. According to uMhlathuze Deputy Mayor Christo Botha's statement, truck drivers anticipate that the proposed system feature will reduce

congestion during hours (Zululand Observer, 2023). The combination of real-time data and decision-making will ease the pressure on roads and reduce expenses.

4.3.2 Feasibility of Data Management in Optimising Traffic Flow

The research emphasises that adopting a data management system could greatly enhance traffic efficiency by forecasting truck movements and significantly reducing congestion points. Linking this system with structures such as the Eyamakhosi truck stop and Transnet staging area would establish an efficient method for overseeing truck arrivals and departures. This forward-thinking strategy aligns with the study's goal by showcasing the potential for efficient data management, which can enhance the effectiveness of current infrastructure by reducing the need for manual traffic regulation.

4.3.3 Complementing Physical Infrastructure with Digital Solutions

Building truck staging areas, such as the Eyamakhosi stop, provides a way to effectively organise truck lines away from highways. Nonetheless, research shows that incorporating a data management system improves these solutions by accurately monitoring and regulating truck movement based on staging capacity and port offloading schedules (Freight news, 2023). This integrated method successfully establishes a data-integrated traffic management process.

4.3.4 Importance of Stakeholder Collaboration

Efficient traffic control at Richards Bay Port depends on the teamwork of groups involved in the process. This research demonstrates that implementing a data management system enhances efficiency by offering a platform for all involved parties to access essential information. The suggested collaborative approach in this study guarantees that those in charge at Transnet, RBCT, and City of uMhlathuze Traffic can jointly make decisions to minimise delays and ensure smooth heavy cargo operations.

4.4 System Design and Implementation

4.4.1 Results of the study using a literature review PRISMA method.

This section describes the results of the study, which was conducted using a literature review following the PRISMA method. The review laid the groundwork for grasping the importance of data handling in improving the flow of heavy cargo traffic at Richards Bay Port. Drawing on information from the literature reviews, findings, and discussions present in this chapter is about the suggested Port Flow Optimiser system designed to tackle the issues identified in managing cargo traffic. This section describes how the system's structure and important

elements were planned to meet the study's goals by linking them to research insights on the user interface design and functionality.

4.4.2 System Overview and Literature Insights

The thorough review of the literature highlighted key aspects of cargo traffic management, including the need for immediate tracking updates, effective communication among stakeholders, and the use of data analytics to predict congestion and improve decision-making processes. The Port Flow Optimiser system proposition seeks to address these requirements by offering a data management platform that monitors truck movements effectively, oversees queues, and alerts stakeholders about congestion in real-time.

4.4.3 System Goals in Context of Literature Review Findings

4.4.3.1 Real-Time Truck Tracking

In the context of real-time truck tracking, the research underscores the importance of managing freight movement using tracking technology, which provides updates on truck locations and traffic density levels. The Port Flow Optimiser efficiently monitors trucks travelling towards Richards Bay Port. The Port Flow Optimiser effectively monitors their journeys and traffic conditions during transit using sensors and Automatic Number Plate Recognition (ANPR) cameras, mirroring industry practices outlined in studies such as Na Li et al. (2019) on the exploration of data applications in traffic pattern prediction.

4.4.3.2 Queue Management and Notifications

In line, with suggestions from previous studies examined, the system offers features for managing queues and sending notifications about congestion to guarantee an arrival of trucks

4.4.3.3 Stakeholder Coordination

Coordination among key entities, such as port authorities and municipal traffic management departments, is critical for managing traffic in port cities. This collaboration involves sharing real-time data, which enables coordination among stakeholders like Transnet and RBCT, in partnership with the city of uMhlathuze. This enhances the collaborative framework, as highlighted by Linlin You et al. (2022) on traffic system data fusion studies.

4.4.4.4 Driver Alerts

Research suggests that informing drivers about traffic fluctuations can effectively lessen traffic jams. The port flow optimisation alerts offer drivers updates on congestion levels and expected arrival times in time, a practice in line with the idea of communication as a tool for alleviating congestion, as per the literature's findings.

4.4.4 Functional Requirements of the Port Flow Optimiser Data Management System

The necessary features of the Port Flow Optimiser were determined by combining information from existing sources and the unique requirements identified for Richards Bay Port. This section describes these features and demonstrates how each feature meets the needs outlined in the reviewed studies.

4.4.4.1 Driver Check-In and Check-Out

To efficiently handle the traffic flow volumes at the port, it is critical to have a planned process for trucks arriving. According to research by Linlin You et al. (2022), the system's truck check-in and check-out procedures aid in maintaining a queue system and providing real-time information on truck numbers.

- Real-Time Truck Tracking: Continuous monitoring of trucks, in time, is critical for traffic management and congestion mitigation, as suggested in big data and traffic forecasting studies. To achieve this goal effectively and promptly detect trucks causing congestion on highways, it is necessary to install sensors and ANPR cameras for tracking and timely notification alerts.
- Queue Management plays a role in reducing traffic congestion, as highlighted in studies and literature sources. The system used for tracking queues assigns identifiers to drivers. It provides them with real-time updates about the status of their queue. This approach aligns with the principles discussed in Methlie's research on decision support systems and real-time management of queues.
- Congestion and Alert Notifications: Studies have shown the significance of congestion alerts as a management strategy tool in optimising port traffic flow efficiently through real-time notifications from the Port Flow Optimiser system to keep drivers and authorities updated about traffic changes and prevent congestion from worsening.
- Reporting and Data Analysis: The study on Reporting and Data Analytics discusses the significance of long-term data analysis for traffic planning, effectively utilising the system's reporting capabilities to assist stakeholders in gaining valuable insights into truck traffic levels and congestion trends for the development of strategic long-term plans.

4.4.5 System Architecture and Data Flow

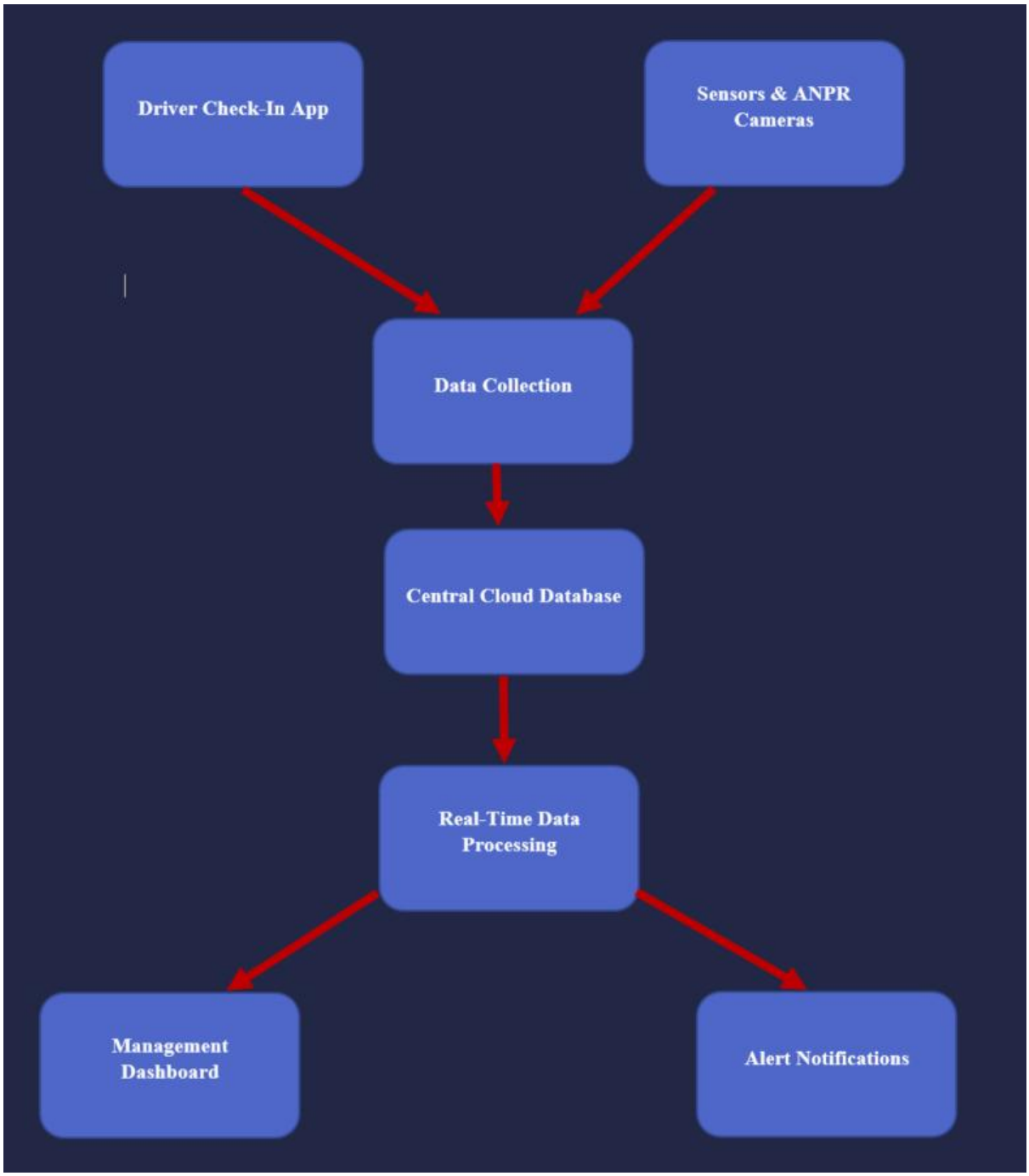
The system setup combines insights from existing research on data-informed decision-making systems and traffic surveillance methods. The diagram below illustrates the process from truck

registration to the information analysis stage, which adheres to established practices outlined in existing literature concerning data-gathering techniques and analytical procedures. In designing the system architecture, integrating data-driven decision-making and real-time traffic monitoring reflects the research objectives and best practices from the literature. This architecture prioritises a seamless data flow enabling efficient, real-time management of heavy cargo traffic around Richards Bay.

The information flows through the system structure in a loop, starting from the driver check-in app, where drivers input their details. This data then merges with information from sensors and ANPR cameras in the data collection module. The central database stores all this combined data and makes it available to the real-time data processing module for examination. The management dashboard displays the analysed data for stakeholders to monitor and make informed decisions. The alert notification system informs drivers of real-time traffic conditions, thereby helping manage traffic in a proactive manner.

Every part of the system is crafted to facilitate the gathering of data and its storage and analysis, in line with research findings from sources. Together, they form a unified and all-encompassing system that addresses the obstacles of traffic congestion at the Port of Richards Bay. The structure of the system enhances traffic flow monitoring and prompt interventions.

Figure 6: Data Flow Diagram of the Port Flow Optimiser Data Management System



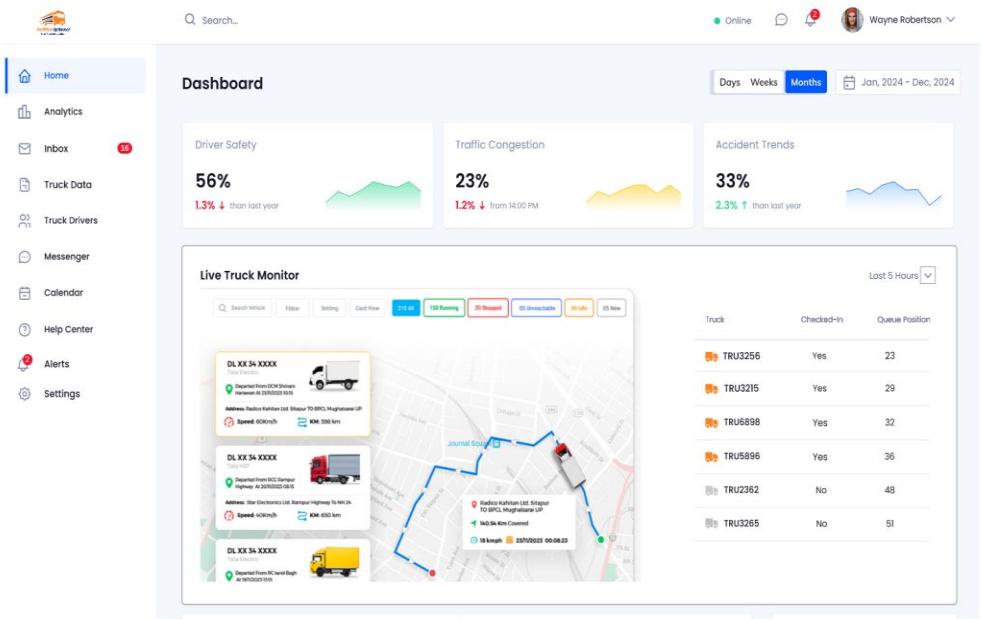
Source: Researcher (2024).

- **Driver Check-In App**: Where drivers input initial check-in data, which feeds into the data collection system.
- **Sensors & ANPR Cameras**: These devices track truck locations and identities in real-time.

- **Data Collection**: Aggregates data from the check-in app and sensors for centralised storage.
- **Central Cloud Database**: Stores collected data securely for processing and retrieval.
- **Real-Time Data Processing**: Analysis incoming data to identify congestion patterns and high-impact zones.
- **Management Dashboard**: Provides stakeholders with real-time insights and visualisations.
- **Alert Notifications**: Sends live updates and congestion warnings to drivers and traffic authorities.

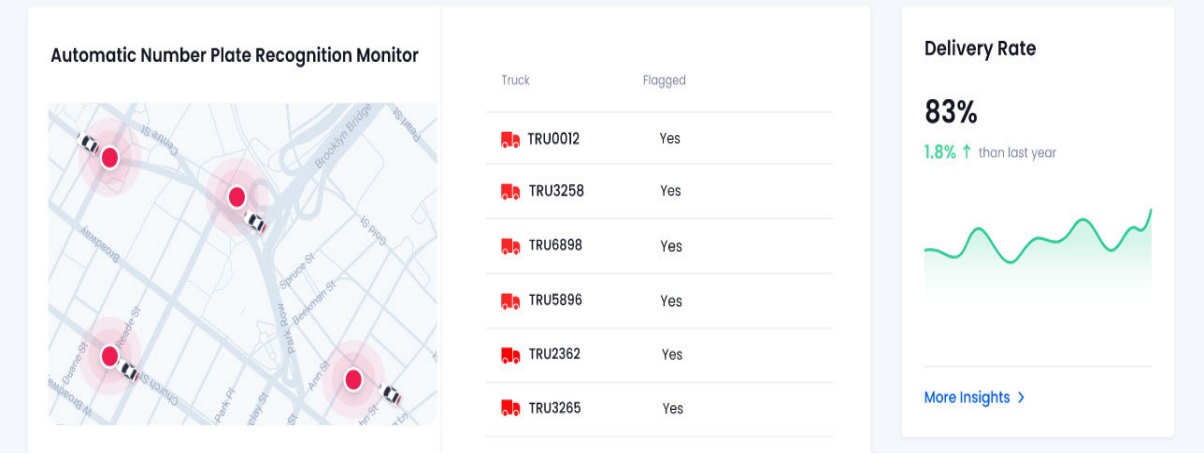
4.4.5 Management Dashboard

Figure 7: Port Flow Optimiser Dashboard screen showing Live Truck monitor on the N2



Source: Researcher (2024).

Figure 8: Port Flow Optimiser Trucks flagged by the Automatic Number Plat recognition as having not checked



Source: Researcher (2024).

The management dashboard aligns with reviewed literature, serving as a hub for real-time and historical data that assists stakeholders in decision-making.

1. **Real-Time Truck Tracking Map**: Literature underscored real-time mapping as critical for traffic monitoring. The dashboard's map shows current truck positions and congestion areas, enabling stakeholders to respond proactively.
2. **Queue and Volume Monitoring**: Following Methlie (2019) recommendations, this feature tracks queue status and sends volume alerts when capacity is near full.
3. **Reports and Analytics**: Analytical reports provide insights on historical congestion trends, supporting long-term planning and operational improvements.

4.4.6 Pseudocode for the Port Flow Optimiser Data Management System

// initialise system variables

Initialise system for truck registration and tracking

Set max_trucks_per_day to value provided by Transnet

// Function to check in a truck

Function check_in_truck (truck details):

If truck details not registered before:

generate unique identifier for truck

assign truck_position in queue based on existing check-ins

Send notification to truck driver with position in queue, expected number of trucks on road, and Transnet capacity

Else:

reject_check_in ("Truck already checked in")

// Function to register truck departure

Function truck departure (truck details):

If truck has unique_identifier:

Mark truck as checked in

Add truck to system queue

Else:

reject_truck_departure ("Truck has not checked in, assign to end of queue")

// Function to scan number plates using ANPR cameras

Function scan_truck_using_ANPR (truck_number_plate):

If truck_number_plate not in system:

notify_driver_of_no_check_in ()

Else:

Log truck_position and location

// Function to communicate real-time updates

Function update drivers ():

For each truck in system:

If truck is approaching congestion:

send_slow_down_notification_to_driver ()

Else:

Continue driving as planned

// Function to check out truck upon delivery

Function check_out_truck (truck details):

Mark truck as checked out

Remove truck from system

// Function to generate daily report for Transnet and city of uMhlathuze

Function generates report ():

Count Checked_in_trucks

count trucks on road

Count trucks that have checked out

Compile report and send to Transnet and City of uMhlathuze officials

4.5 Conclusion

This chapter discussed results that highlight the significance of managing data to improve the flow of heavy goods traffic at Richards Bay Port. By studying traffic data, it was feasible to spot congestion trends and suggest a data management system that matches with infrastructure enhancements like setting up truck stops and staging zones. The conclusions of this research stress the importance of combining infrastructure with data systems for efficient monitoring and communication among various involved parties in real-time situations.

The suggested system aims to reduce traffic and facilitate resource distribution to help enhance the port's operations and ease congestion on public roads. The system's results are derived from a thorough study of existing literature, and the design of the port flow Optimiser clearly shows how data systems can improve traffic control at Richards Bay Port efficiently and effectively. By incorporating check-in procedures and real-time monitoring alongside queue administration and reporting features, the system design showcases its adherence to established practices supported by literature in traffic control communication and congestion mitigation. Conclusions and recommendations derived from these discoveries are discussed in the next chapter.

Chapter Five: Recommendations and Conclusions

5.1 Introduction

This final chapter discusses the findings of the study, discusses their implications, offers recommendations, identifies study limitations, and suggests future research directions. The chapter addresses the research questions, reflects on the achievement of study objectives, and concludes with a holistic overview of the research outcomes considering the challenges and historical context surrounding traffic congestion at the port.

5.2 Discussion of Research Findings

The findings underscore the potential and feasibility of an active data management system to address heavy truck congestion while reducing hazards associated with traffic build-up. Each research question and objective guided the study's structure, ensuring that the conclusions aligned with the aim of optimising traffic management and enhancing road safety through data-driven solutions.

5.2.1 Using Data Management to Improve Decision-Making and Alleviate Congestion

The research highlights that data management is critical in creating informed, proactive strategies to mitigate congestion-related hazards. By capturing and analysing real-time data on traffic flows and truck arrivals, authorities can better predict congestion points and high-risk zones. The findings demonstrate that, with access to precise data, stakeholders can anticipate peak times and respond to emerging issues efficiently, minimising disruptions and enabling smoother traffic flow.

5.2.2 Designing a Data Management System for Traffic Data Collection, Storage, and Analysis

The proposed data management system incorporates advanced traffic data collection and storage methods, including sensors, ANPR cameras, and a mobile application for truck check-in. This design enhances data accessibility for stakeholders at Richards Bay Coal Terminal (RBCT), Transnet, and the city of uMhlathuze. By centralising traffic data and allowing for comprehensive real-time analysis, the system addresses critical issues, such as truck staging delays, unexpected congestion surges, and slow response times. Through improved data visibility, the system empowers traffic authorities to act promptly to reduce congestion and respond to hazards, ensuring smoother road use.

5.2.3 Effective Communication and Dissemination of Real-Time Data

Efficient, real-time communication between stakeholders and truck drivers is critical in addressing congestion hazards. The system's alert notifications provide drivers with critical updates about their position in the queue, estimated waiting times, and road conditions. This continuous flow of information enables truck operators to adjust their driving behaviours, reducing the likelihood of accidents and congestion on major routes. Furthermore, the system improves road safety by providing warnings on impending congestion and high-risk zones. It reduces strain on traffic enforcement officers who would otherwise need to manage manual traffic controls.

5.2.4 Identifying Key Data Sources and Types for Traffic Management

The study identified essential data sources, such as traffic density on key highways, truck arrival times, cargo types, and queue lengths. These data types enable authorities to understand congestion patterns and develop predictive models to prevent potential hazards, including accidents and traffic backups. Leveraging this data allows stakeholders to prepare for and respond to high-volume traffic effectively, enhancing road safety and alleviating congestion-related hazards.

5.3 Achievement of Study Objectives

The study achieved its key objectives, which are summarised below:

The current traffic data is being analysed to identify trends, areas of congestion, and areas of significant impact, particularly on the N2 and the John Ross Highway that connects to the Port of Richards Bay.

Analysis of current traffic data highlighted peak times and critical congestion points on the N2 and John Ross Highway. This strategic insight supports efforts to minimise accident risks and enhance the safety of both trucks and the public.

The study aims to investigate the viability of utilising a developed data management system to enhance the flow of heavy cargo and reduce the impact on local infrastructure and the environment.

The current literature analysis revealed the feasibility of using data management in real-time to enable proactive decision-making. This, in turn, can help reduce congestion points, enhance traffic flow, and alleviate safety risks associated with heavy traffic.

A system is proposed that incorporates real-time data collection, visualization, and communication tools for various stakeholders, including the Richards Bay Coal Terminal (RBCT), Transnet, and the traffic authorities in the City of uMhlathuze.

Developing a data management system for real-time monitoring can enhance coordination among stakeholders such as Transnet, RBCT, and the city of uMhlathuze. This integrated system can provide a reliable way to communicate real-time data, allowing stakeholders to anticipate traffic issues and minimise risks associated with unmanaged truck volumes.

5.4 Recommendations

The findings lead to several actionable recommendations for stakeholders managing heavy cargo traffic at the port of Richards Bay:

5.4.1 Adopt and Implement the Data Management System

Stakeholders should adopt the proposed system to actively monitor and manage truck congestion, thereby preventing delays and related hazards. Expanding the system to include additional cargo operations would further ensure effective traffic flow and road safety.

5.4.2 Enhance Training and Compliance for Truck Drivers

It is recommended that truck drivers be trained on the check-in system and the interpretation of traffic notifications to enhance system compliance. Such training is expected to reduce highway queueing, thereby decreasing congestion-related accidents and other hazards.

5.4.3 Establish Additional Staging Areas

Increasing the number of designated staging areas before trucks approach the port is recommended to prevent congestion on the N2 and John Ross Highway, thereby mitigating risks to local communities and enhancing road safety.

5.4.4 Develop a Continuous Feedback Mechanism

It is recommended that there is a regular evaluation of the system's performance; feedback from stakeholders will help refine the system and address any operational challenges, adapting to the evolving needs of port traffic.

5.5 Proposed System Functionality

5.5.1 Part A Port Flow Optimiser: App based (Part A)

The proposed Port Flow Optimiser system includes a mobile app designed specifically for drivers and my companies. This app-based functionality facilitates the management of truck entry and exit processes through a user-friendly digital interface, supporting data collection at every stage.

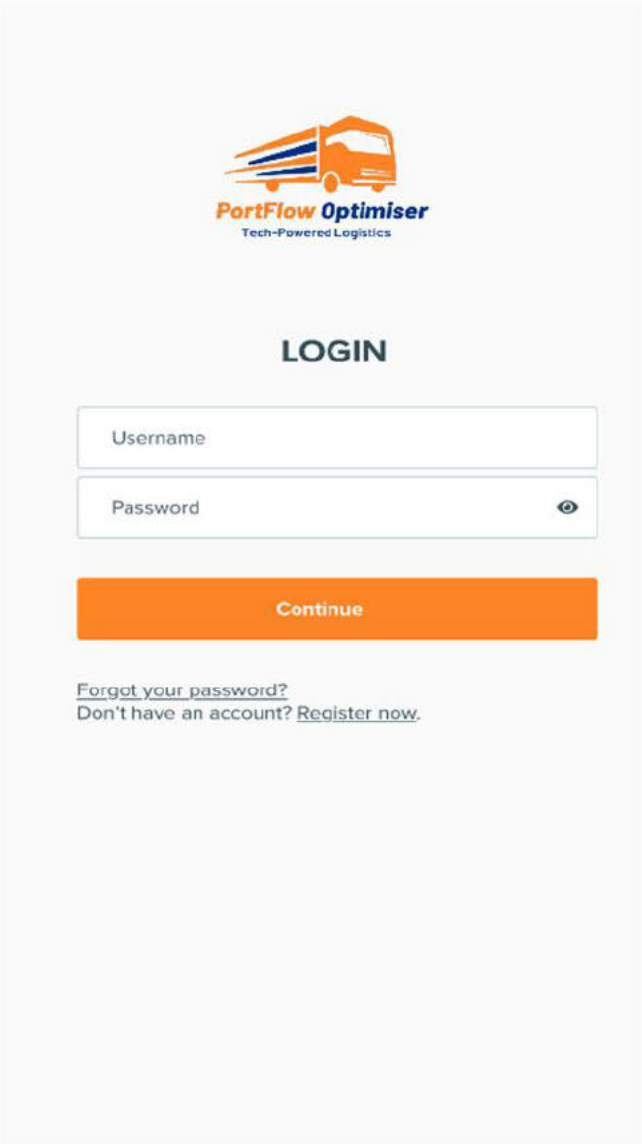
Figure 9: Proposed Name of the App or System



Source: Researcher (2024).

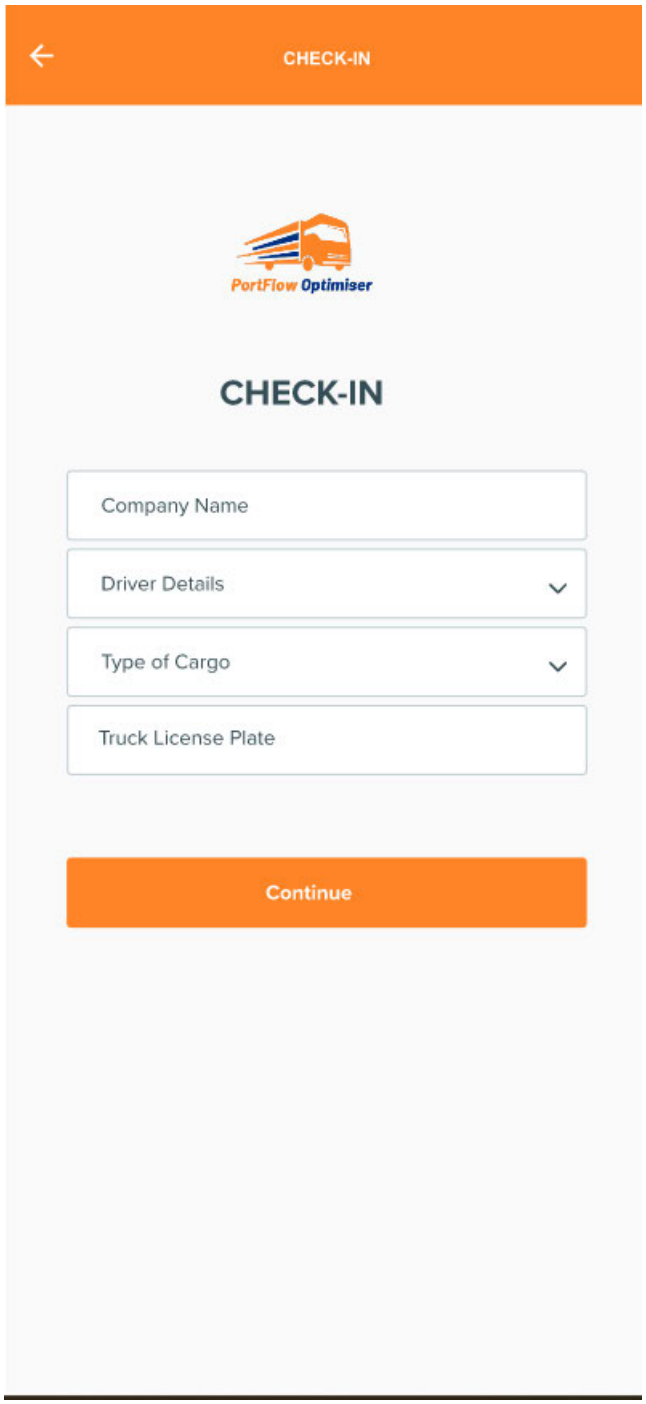
The app starts with a registration screen, where users create an account, allowing secure access for both drivers and dispatch managers. Once registered, the check-in screen enables users to input essential data such as driver details, company name, cargo type, and the truck's license plate. This check-in data is critical for initiating the tracking process as trucks depart toward Richards Bay Port.

Figure 10: Login / Registration Screen



This screen provides a secure entry point for users. It features options for user login, registration, and password recovery. **Purpose**: To ensure that only authorized drivers and dispatchers access the system, securing data integrity and user-specific updates

Figure 11: Check in Screen



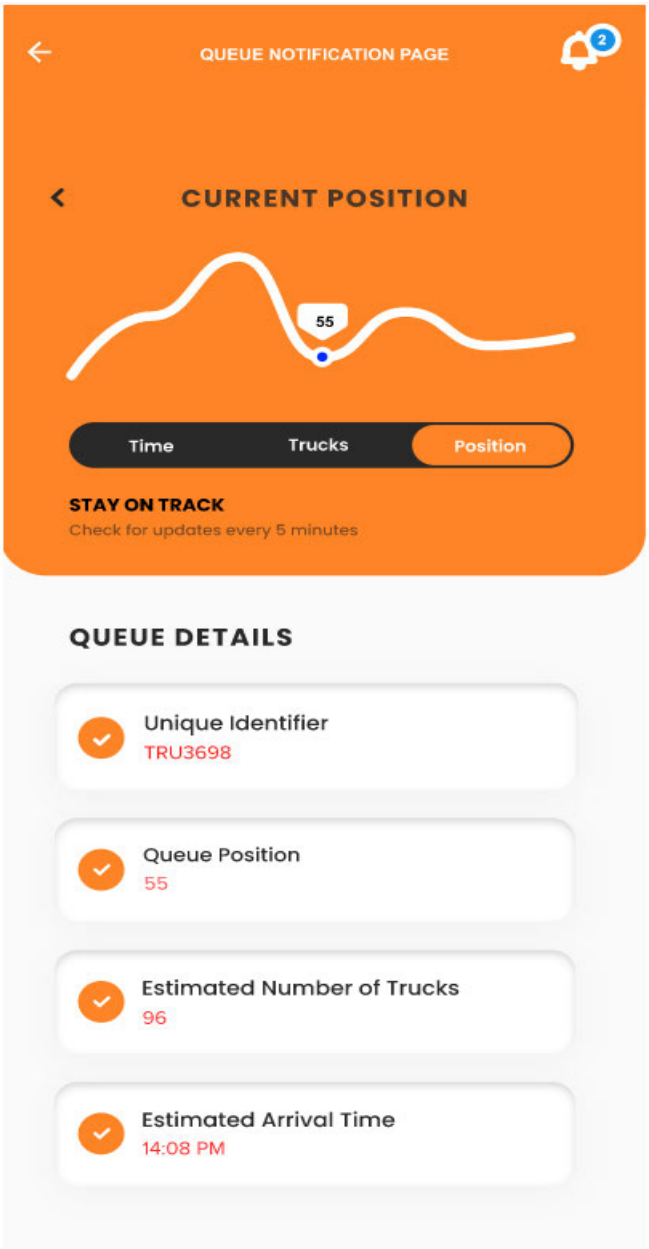
The check-in screen is designed for truck companies to input essential data, including the driver's details, company name, cargo type, and license plate number. This information is populated by the truck company as trucks are dispatched toward Richards Bay Port.

Source: Researcher (2024).

Source: Researcher (2024).

The **Queue Notification Screen** provides output data to the user, including the truck's unique identifier, current queue position, and an estimated number of trucks expected for the day, week, and month. It also calculates an estimated arrival time based on the check-in timestamp and anticipated travel duration, providing critical scheduling information for the journey.

Figure 12: Queue Notification Screen



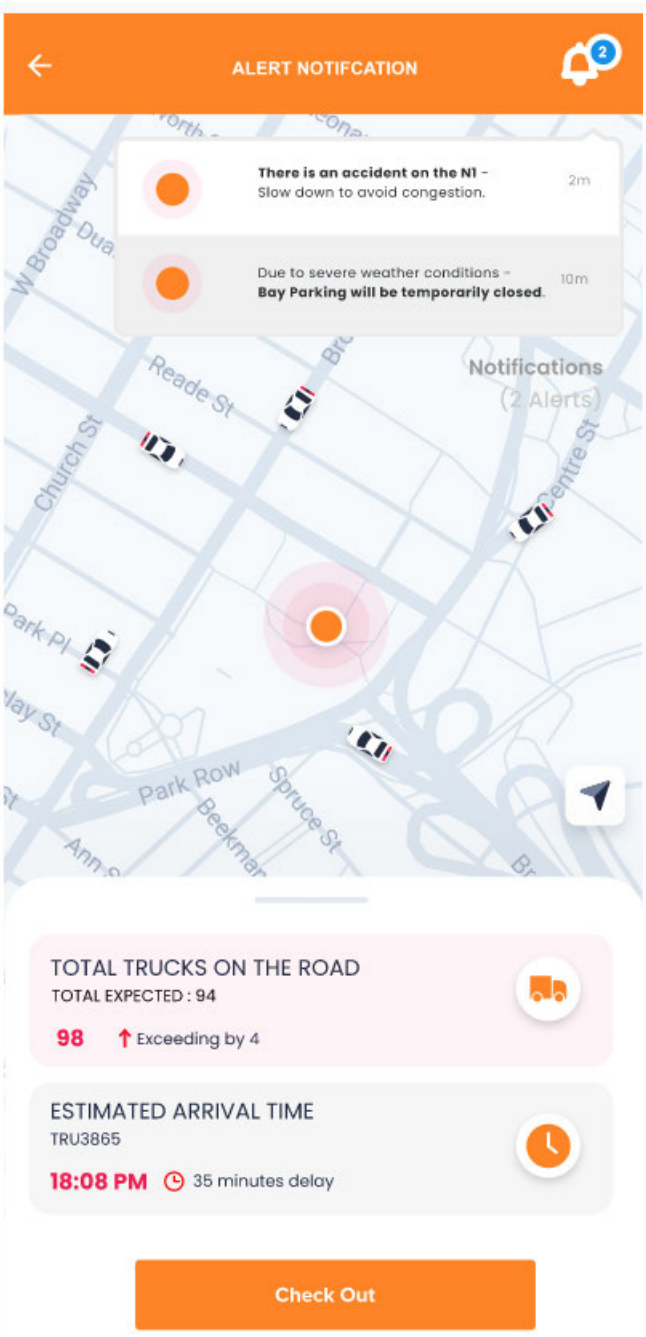
This screen is key to tracking the truck's queue position. It displays:

- A unique identifier (reference number) assigned to each truck,
- The truck's position in the queue,
- Estimated daily, weekly, and monthly truck volumes,

Source: Researcher (2024).

The alert notifications screen displays important traffic updates for real-time monitoring, including the total number of trucks en route, real-time GPS-based congestion data, and instructions to adjust speed if congestion is detected. Additionally, this screen highlights whether the truck volume has exceeded expected levels for the day, helping drivers plan accordingly.

Figure 13: Alert Notification Screen



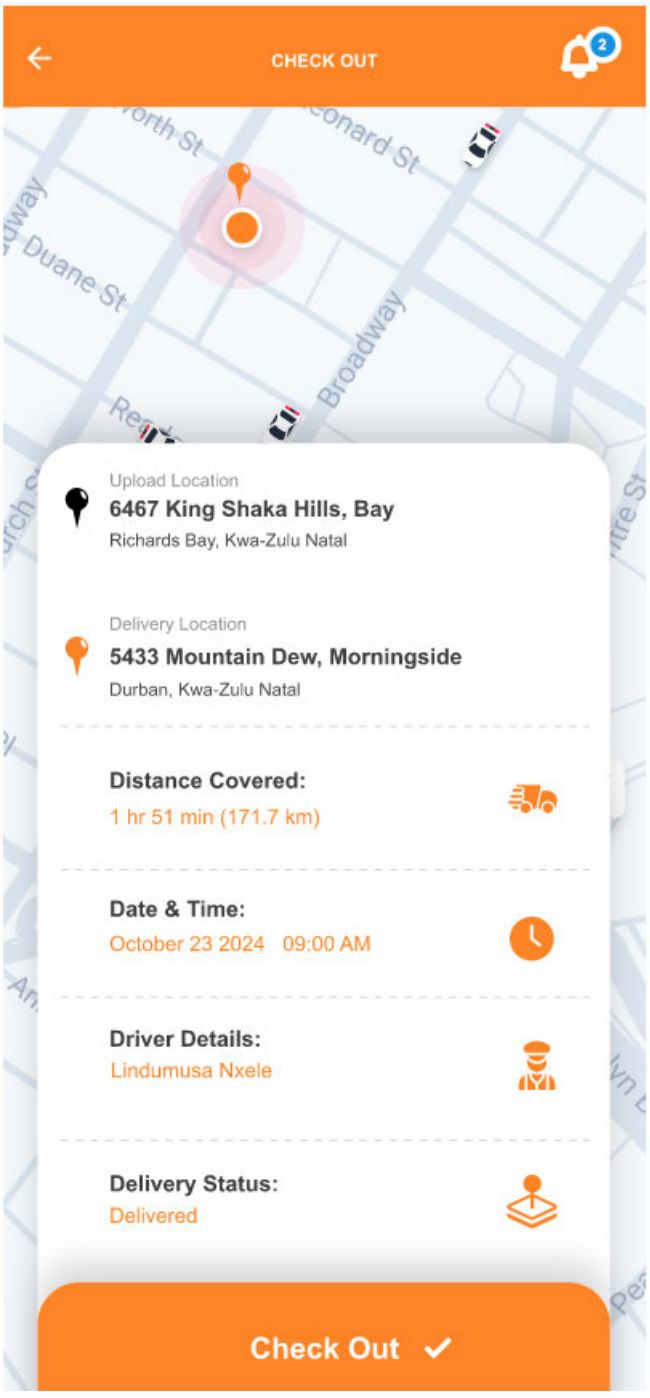
On this screen, users receive real-time notifications on the traffic flow to Richards Bay Port. Features include:

- GPS updates showing truck locations,
- Alerts to slow down if congestion is detected,
- A count of trucks en route to the port,

Source: Researcher (2024).

Finally, the checkout screen enables drivers to complete their trips, displaying a summary of the journey, including distance covered, driver details, and delivery status. This final step completes the data cycle, ensuring comprehensive logging of truck movements from entry to exit.

Figure 14: Check out screen

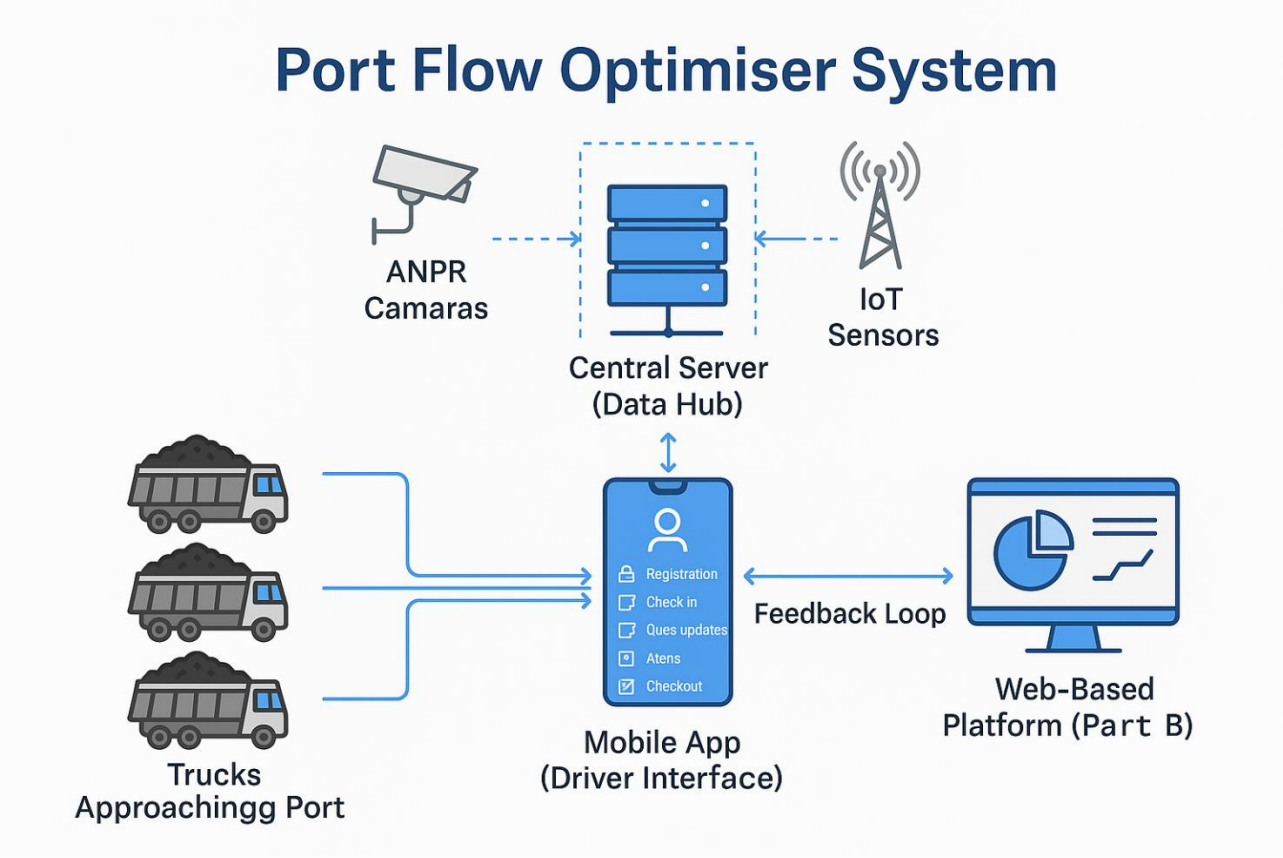


The final screen provides a summary upon delivery. It displays the driver's details, distance covered, and delivery status, ensuring that the system's tracking cycle completes with clear records for each trip.

Source: Researcher (2024).

This app-based functionality represents part A of the system, designed for on-the-road data collection and real-time management by drivers and mining companies. Part B of the system, a web-based platform, will be accessible to stakeholders such as Transnet and other relevant authorities, supporting oversight and strategic decision-making on traffic management at Richards Bay Port. The proposed port flow optimiser system includes a mobile app, designed with Adobe XD, to showcase how data collection would be managed for drivers and my companies. This app-based functionality enables efficient truck management by gathering essential information from entry to exit through a streamlined digital interface

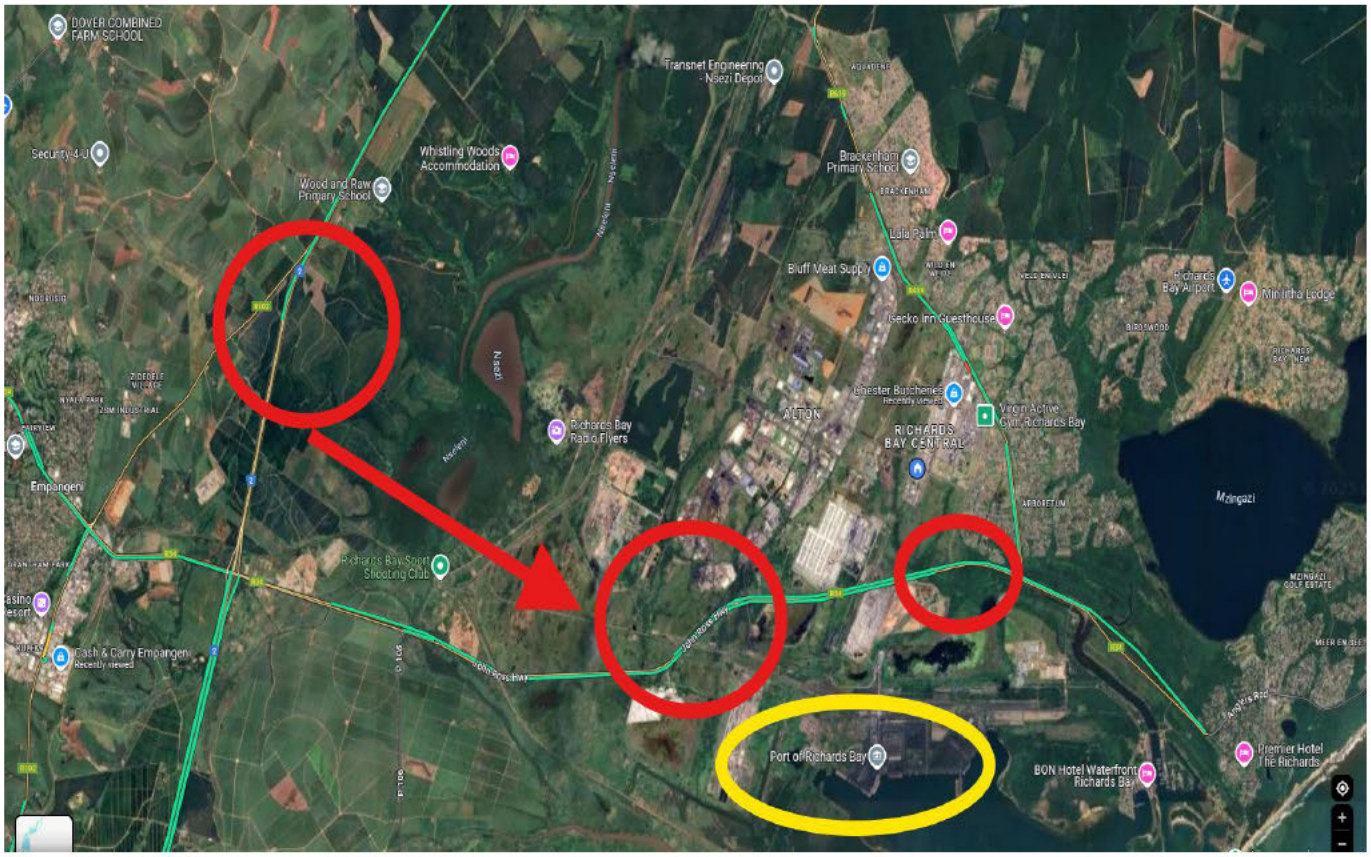
Figure 15: Conceptual diagram (Port flow Optimiser)



The diagram illustrates the Port Flow Optimiser System Trucks approaching the port interact with the system through a mobile application that enables driver registration, check-in, queue updates, attendance, and checkout. Data is collected from ANPR (Automatic Number Plate Recognition) cameras and IoT sensors and transmitted to a central server (data hub). This server processes and relays information to both the mobile app and a web-based platform (Part B), creating a real-time feedback loop that enhances decision-making

Source: Researcher (2024

Figure 16 Map illustrating high impact traffic zones



The map illustrates high-impact traffic congestion zones on the N2 and John Ross Highway leading to the Port of Richards Bay, where heavy truck congestion significantly affects traffic flow and road safety.

Source: Researcher (2024)

Table 1 Summary of Current Challenges vs. Proposed Data-Driven Solutions (Port Flow Optimiser)

Current Challenge	Proposed Data-Driven Solution(Port Flow Optimiser)
Unpredictable truck arrivals causing bottlenecks	Mobile check-in app with scheduling and real-time tracking
Manual queueing systems leading to traffic overflow on highways (e.g., N2, John Ross)	Automated queue management via centralised data management system
Lack of real-time communication between drivers and the Port	Alert notification system with congestion warnings and route guidance
Congestion hotspots unidentified until crises occur	Real-time sensor + ANPR data to visualise and predict congestion zones on live dashboard
Inadequate staging areas and unregulated access to port	Data-driven planning to establish new staging areas and regulate access based on truck volumes

Limited visibility for stakeholders on traffic trends and performance	Centralised dashboard providing real-time analytics and historical reports for planning and decision-making
Dependency on manual enforcement by traffic officers	Digital system for automatic detection of non-compliant trucks via ANPR + alerts
Environmental and community impact due to congestion and emissions	Reduced idle times and truck density through proactive traffic control, improving sustainability and reducing pollution

Table 1 This summary table outlines the primary heavy cargo traffic management challenges identified through research and matches each with the proposed system's data-driven solution

5.6 Limitations of the Study and Directions for Future Research

While the study presented a viable data-driven solution to traffic congestion, limitations suggest areas for further research:

5.6.1 Scope of Data Collection

The study primarily relied on secondary data and literature, which may not fully represent the current conditions. Future research could incorporate primary data from a pilot implementation to validate the system's effectiveness in real-time settings.

5.6.2 Specific Focus on Richards Bay

While the study focused on Richards Bay, applying these findings in other locations would require additional customisation. Future studies could explore the adaptability of this system to other high-traffic ports.

5.6.3 Stakeholder Engagement and Policy Support

The system's effectiveness depends on stakeholder cooperation, which may require supportive policies and resources. Future research could examine strategies for encouraging consistent engagement and creating policies that foster data-driven traffic management.

5.6.4 Data Privacy and Security Concerns

Managing sensitive data, such as driver details and cargo information, necessitates data security protocols. Future studies should consider privacy measures to secure information and protect against data breaches

5.7 Overall Study Conclusion

In conclusion, this study used a data management system to optimise traffic flow and decision-making to address the logistical and safety challenges posed by heavy cargo truck congestion at the Port of Richards Bay. By integrating real-time data, the proposed system provides stakeholders with essential insights, enabling them to proactively manage truck movements, reduce delays, and alleviate safety risks. The system's potential to communicate and monitor traffic in real time plays a critical role in minimizing hazards associated with heavy cargo congestion, such as accidents, infrastructure strains, and community safety concerns.

Ultimately, the study illustrates how an integrated data-driven approach can enhance urban traffic management, support public safety, and promote infrastructure resilience. The recommendations, limitations, and future research directions underscore the need for continued collaboration, innovation, and adaptation in the field of logistics and traffic management. Overall, this research provides a foundational model that stakeholders at the Port of Richards Bay and other locations can use to implement sustainable traffic solutions, supporting South Africa’s economic growth in global trade while safeguarding public well-being and infrastructure integrity.

This research offers a solution to the problem of traffic jams caused by heavy cargo trucks at Richards Bay Port by highlighting the importance of effective data management in improving traffic efficiency and decision-making in industrial zones with significant impact. Using a data management system, as demonstrated in this study, The analysis highlights how up-to-date information can simplify port operations, reduce traffic risks, enhance public safety measures, and effectively address pressing issues impacting both infrastructure and community well-being in Richards Bay.

The study argued that traffic jams at the Port of Richards Bay stem from standing infrastructure issues. KZN Transport and Daily Maverick reported in 2023 that the switch from rail to road transportation, following the breakdown of the railway system, is a major factor. This change has resulted in reliance on roads for moving quantities of goods, which has caused significant traffic congestion on highways, like the N2 and John Ross Highway (as featured on Carte Blanche in 2023). The proposed data management system addresses these issues by tracking truck movements to reduce waiting times and ensure timely arrival of trucks at the port. The above is critical for ensuring a secure flow of heavy cargo traffic.

The results of this study support the importance of using data to make decisions when it comes to handling traffic. This aligns with what other studies have found regarding the benefits of using real-time data for predicting traffic patterns in cities and busy logistics settings (Na Li et al., 2020). Real-time data analysis from sensors and ANPR cameras, along with data from apps, facilitates accurate predictions of peak traffic times and risky areas for port officials and traffic managers (You et al., 2019). Monitoring truck queues and promptly informing drivers of their positions is essential to reduce waiting times on highways. This helps prevent accidents and reduces stress on infrastructure (Banya, 2023).

The study demonstrated how the system could successfully meet the study goals by improving traffic flow and enhancing safety, as explained below.

Objective 1: The study clearly understood current traffic data patterns, congestion points, and high-impact points, particularly on the N2 and the John Ross Highway, which leads to the Port of Richards Bay, and emphasised the importance of data management in optimising traffic flow. A comprehensive data system enables better anticipation and control of traffic volumes in the study areas, leading to their reduction (Na Li et al., 2020).

Objective 2 revealed a possibility to examine in real time the traffic information to identify peak congestion periods and trouble spots on the N2 and John Ross Highway, a critical step in minimising accidents and enhancing overall road safety. The new system does not just tackle traffic jams but also works towards creating a lasting strategy for managing traffic in the long run by promoting ongoing communication and sharing of information to improve cooperation among stakeholders.

By designing the system to provide an open method of handling traffic information for Richards Bay Coal Terminal (RBCT), Transnet, and the city of uMhlathuze, Objective 3 was achieved and supported an approach to traffic management. The information coincides with conclusions drawn from the literature consulted on data distribution. These studies suggest that collaborative data platforms enhance the understanding of situations for parties and stakeholders and enable them to react promptly to traffic disturbances (Banya, 2023). Moreover, the new data system deals with safety-related worries due to the number of trucks on the roads. The focus of the study on updates and warnings about dangers is to reduce the chances of accidents, an issue for neighbourhoods near these roads, and promote secure transportation of heavy goods with minimal risks (Makhaye, 2023). Moreover, the system's ability to relieve law enforcement officers from handling traffic congestion issues may enable

them to redistribute their efforts to aspects of traffic law enforcement, thus improving overall road safety in the City of uMhlathuze.

In support of the adopted desktop methodology, the study justified this approach based on the availability and richness of existing document sources, which provided sufficient data for a comprehensive qualitative analysis. Through a blend of examining past and current data trends and crafting a system design rooted in the tried and tested methods found in literature, this study not only offers a remedy to today's congestion woes but also sets up a lasting model that can evolve with future needs.

The study showcases that utilizing technology to regulate traffic movement and improve decision-making processes can help alleviate hurdles at Richards Bay and other busy industrial ports. The literature-supported data management framework and the presented suggestions establish a foundation for improving traffic control and public safety measures in South Africa, thereby fostering development and advancing urban infrastructure. To sum up, the study provides a data-focused strategy for overseeing traffic in Richards Bay efficiently. By making use of data insights and quick decision-making along with traffic monitoring in real time, this method gives a forward-thinking solution that matches current worldwide directions in improving logistics efficiency and public safety.

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Appendices

Appendix A: Ethical Clearance Letter



Mr Lindumusa Justice Nxele (206516132)
School Of Man Info Tech &Gov
Westville

Dear Mr Lindumusa Justice Nxele,

Original application number: 00028080
Project title: Optimising heavy cargo traffic management: Enhancing decision-making through effective data management at the port of Richards Bay

Exemption from Ethics Review

In response to your application received on 23 September 2024, your school has indicated that the protocol has been granted **EXEMPTION FROM ETHICS REVIEW.**

Any alteration/s to the exempted research protocol, e.g., Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through an amendment/modification prior to its implementation. The original exemption number must be cited.

For any changes that could result in potential risk, an ethics application including the proposed amendments must be submitted to the relevant UKZN Research Ethics Committee. The original exemption number must be cited.

In case you have further queries, please quote the above reference number.

PLEASE NOTE:
Research data should be securely stored in the discipline/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours sincerely,

Prof Maria Isabel De Azevedo Martins
Academic Leader Research
School Of Man Info Tech &Gov

UKZN Research Ethics Office
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Website: http://research.ukzn.ac.za/Research-Ethics/

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

INSPIRING GREATNESS

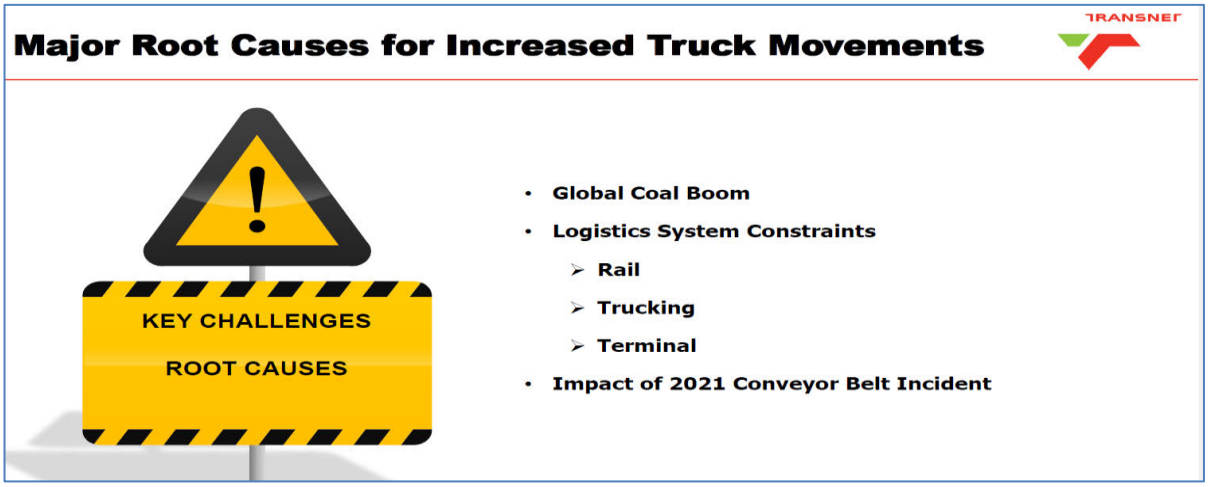
Appendix B: Trucks Queuing from Mtubatuba on the N2



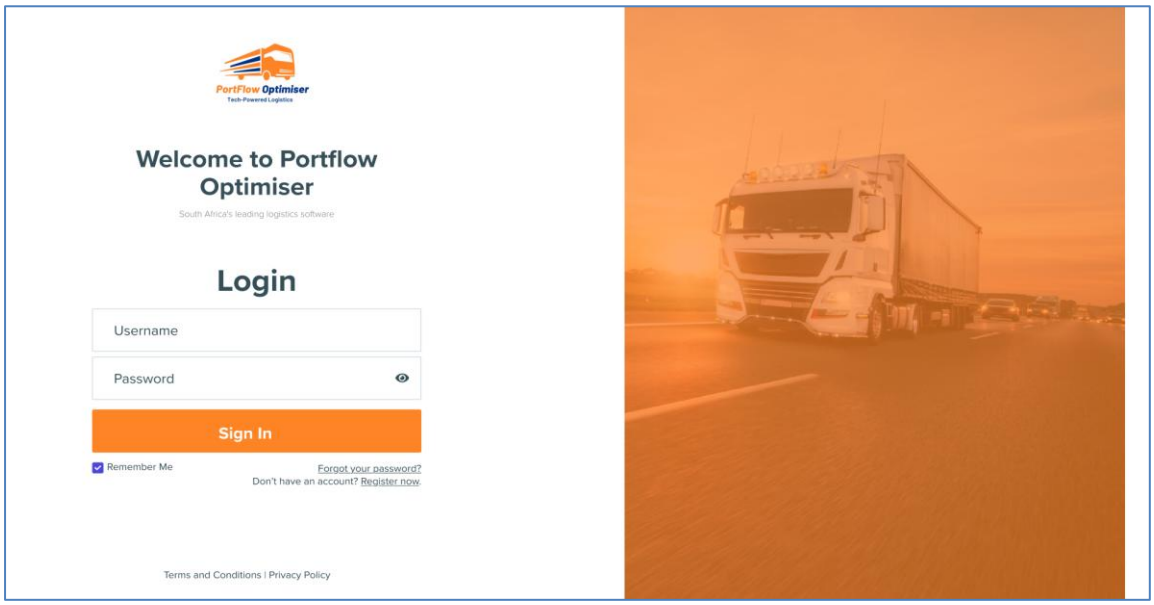
Appendix C: Eyamakhosi Truck Stop Opening Soon



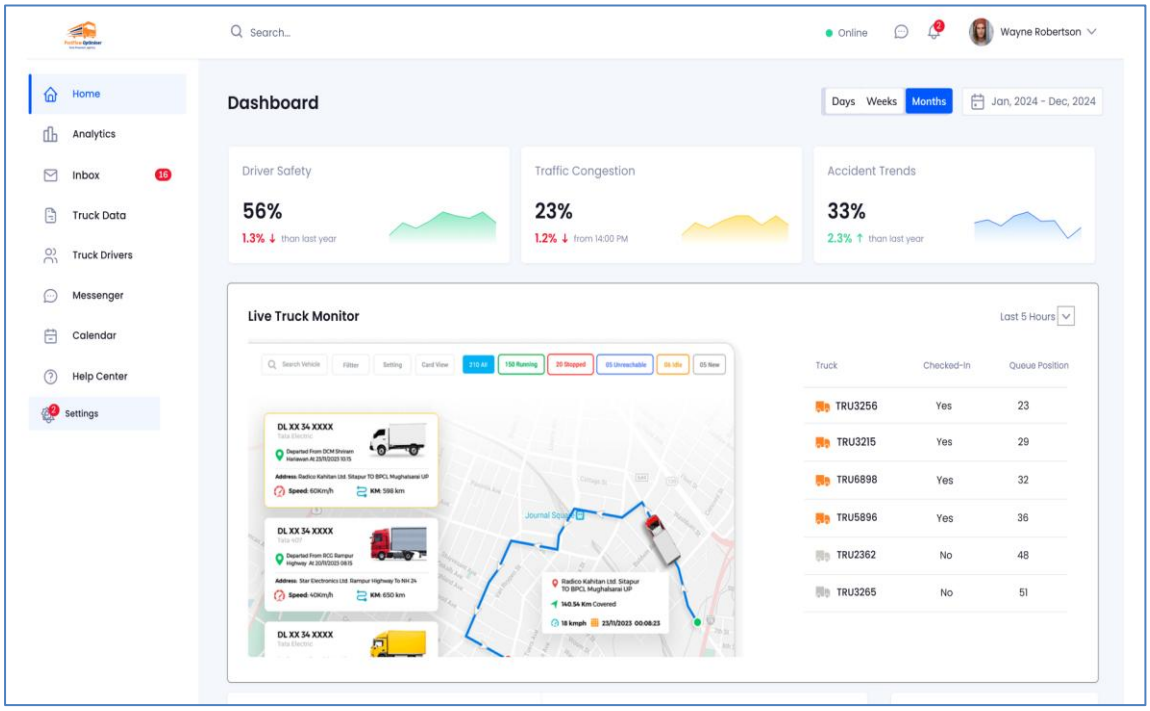
Appendix D: Causes for Increased Truck Movements



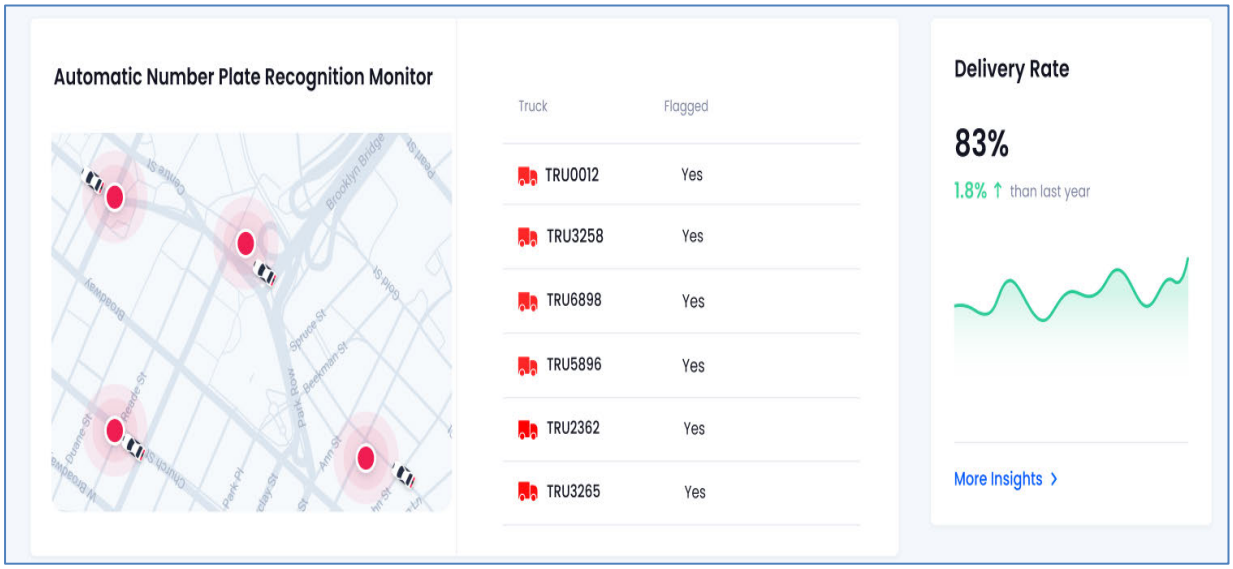
Appendix E: Login Screen of the Web Application for Port Optimiser



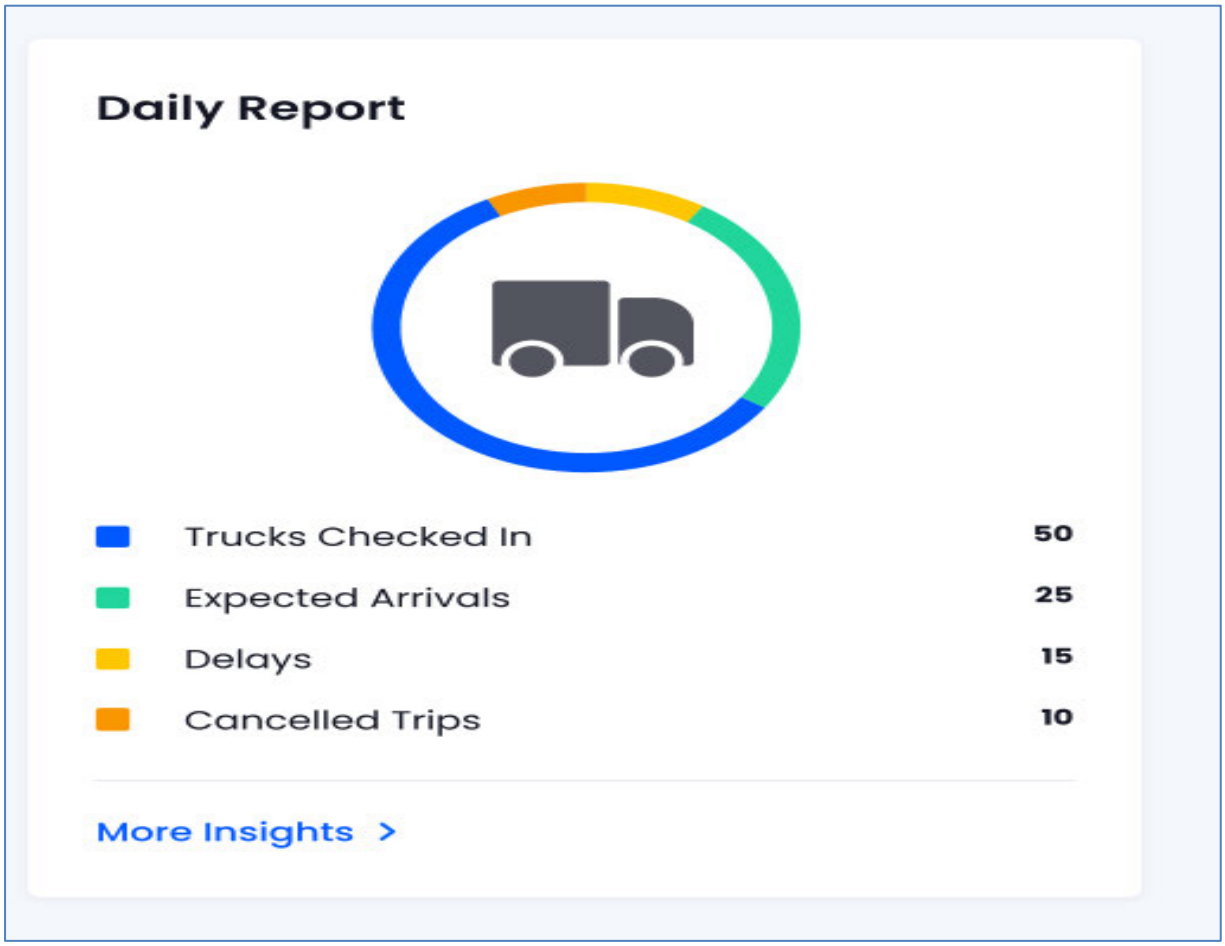
Appendix F: Dashboard Screen of the Web Application



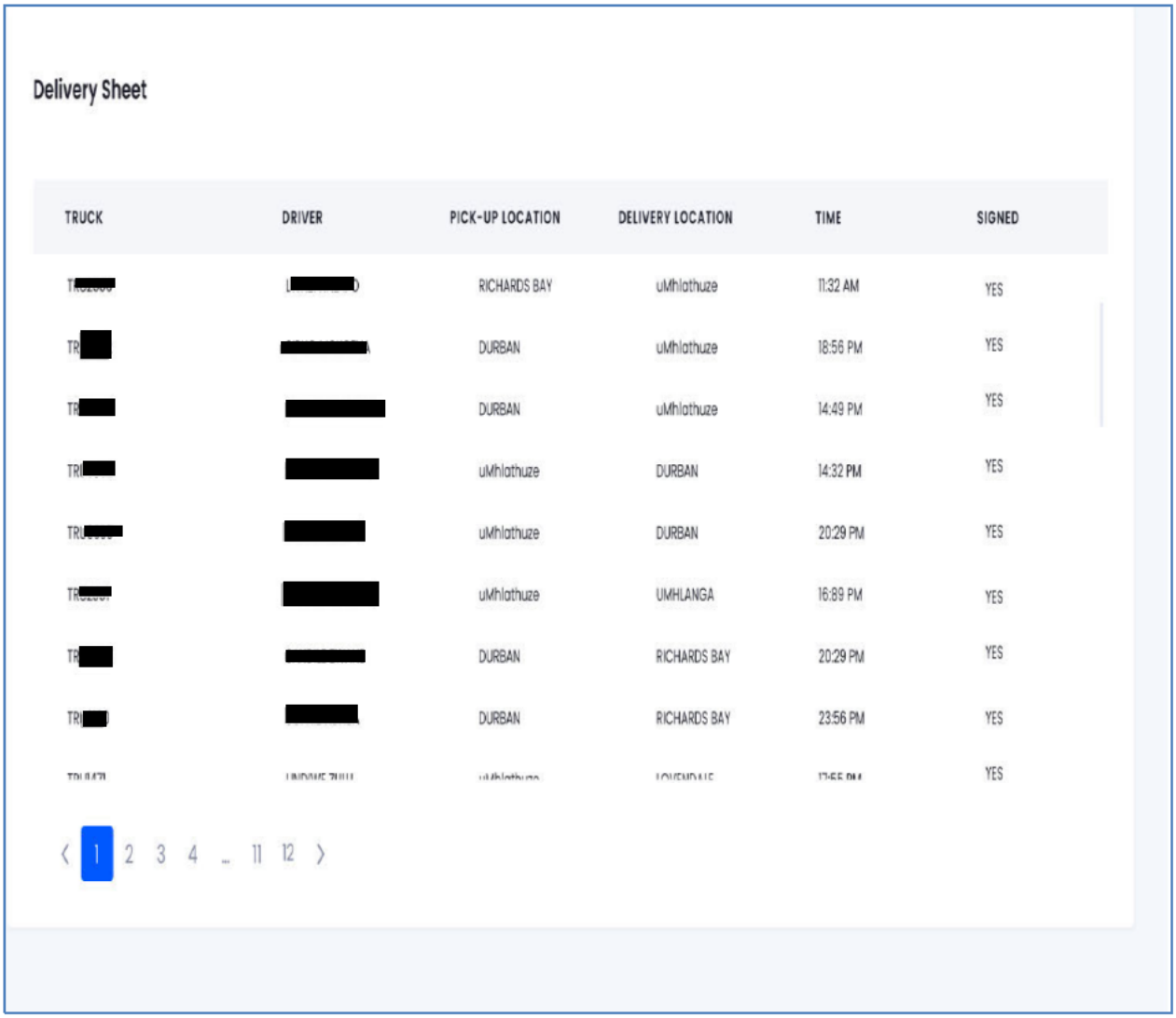
Appendix G : Automatic Number Plate Recognition on heavy cargo trucks that have not checked in



Appendix H: Daily delivery report of heavy cargo trucks



Appendix I : Delivery Sheet report from the Port Flow Optimiser



Delivery Sheet

TRUCK	DRIVER	PICK-UP LOCATION	DELIVERY LOCATION	TIME	SIGNED
[redacted]	[redacted]	RICHARDS BAY	uMhlathuze	11:32 AM	YES
[redacted]	[redacted]	DURBAN	uMhlathuze	18:56 PM	YES
[redacted]	[redacted]	DURBAN	uMhlathuze	14:49 PM	YES
[redacted]	[redacted]	uMhlathuze	DURBAN	14:32 PM	YES
[redacted]	[redacted]	uMhlathuze	DURBAN	20:29 PM	YES
[redacted]	[redacted]	uMhlathuze	UMHLANGA	16:89 PM	YES
[redacted]	[redacted]	DURBAN	RICHARDS BAY	20:29 PM	YES
[redacted]	[redacted]	DURBAN	RICHARDS BAY	23:56 PM	YES
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	YES

< 1 2 3 4 ... 11 12 >

Appendix J: Trucks Deadlocked on the N2 towards Richards Bay port



Appendix K: Summary of Studies Included in the PRISMA Systematic

Table 1 Summary of studies included in the Prisma Systematic Literature Review

Author/Year	Studies	Aim of the Study	Research Findings	Intervention
Bolodurina and Speshilov (2023a)	Application of fuzzy logic rules for data analysis and decision-making in cargo transportation management under conditions of uncertainty.	Application of fuzzy logic rules for decision-making in cargo transportation management under uncertainty.	Fuzzy logic rules assist in decision-making in uncertain environments, improving cargo traffic management.	Application of fuzzy logic for enhanced decision-making in cargo transport management.
Bolodurina and Speshilov (2023b)	Mathematical and instrumental means of providing an intelligent decision support system for cargo traffic management.	Developing an intelligent decision support system for cargo traffic management.	Proposed mathematical tools and decision support systems to enhance efficiency in cargo management under uncertainty.	Integration of mathematical tools for intelligent decision-making in cargo traffic management.
Carrer, Ferson and Green (2020)	Optimising cargo loading and ship scheduling in tidal areas.	To Optimise cargo loading and ship scheduling in tidal areas.	Developed an optimisation model for cargo loading and ship scheduling in tidal regions, improving	Effective Cargo loading and scheduling optimisation for tidal areas.

			logistics efficiency.	
Chen et al. (2021)	Pragmatic real-time logistics management with traffic IoT infrastructure: Big data predictive analytics of freight travel time for Logistics 4.0	Predictive analytics of freight travel time for Logistics 4.0 with IoT infrastructure.	Big data and IoT infrastructure can predict freight travel times and optimise logistics management in real-time.	Use of IoT and big data predictive analytics to improve freight management in Logistics 4.0.
Dzemydiene et al. (2021)	Integration of Multi-Criteria Decision Support with Infrastructure of Smart Services for Sustainable Multi-Modal Transportation of Freights.	The Integration of decision support with smart services for sustainable freight transportation	Proposed multi-modal transportation solutions for sustainable freight transport, emphasising smart services integration.	Multi-criteria decision support systems integrated with smart transportation infrastructure.
Gattuso and Pellicano (2023)	Handling Units Fleet Management in an Automated Container Port: Assessment by a	The paper aims to assess the impacts due to the automation of Handling Units by using a simulation approach.	Simulation approaches improved fleet management at container ports,	A Simulation based fleet management for automated container ports.

	Simulation Approach.		optimising resource usage.	
Hu et al. (2019)	Two time-varying and state-dependent fluid queuing models for traffic circulation systems.	Time varying queuing models for traffic circulation systems	Proposed fluid queuing models to optimise traffic circulation, improving flow in congested systems.	Time-varying, state-dependent queuing models to optimise traffic flow.
Ilio et al. (2021)	Preliminary design of a fuel cell/battery hybrid powertrain for a heavy-duty Yard truck for port logistics.	Designing a hybrid powertrain for heavy-duty trucks in port logistics.	Proposed a fuel cell/battery hybrid powertrain for port logistics, improving energy efficiency and reducing emissions.	Development of hybrid powertrain systems for port truck logistics.
Jia, Meng and Kuang (2021)	Equitable Vessel Traffic Scheduling in a Seaport.	Equitable vessel traffic scheduling in seaports	Developed equitable scheduling models for managing vessel traffic, optimising throughput and reducing delays.	Equitable vessel scheduling to enhance efficiency in seaport operations.

Menelaou et al. (2021)	Joint Route Guidance and Demand Management for Real-Time Control of Multi-Regional Traffic Networks.	To Propose a joint route guidance and demand management strategy for multi-region networks with macroscopic traffic dynamics.	Joint route guidance and demand management strategies improved real-time traffic network control.	Real-time traffic network management through joint route guidance and demand management.
Modi et al. (2019)	Minimization Of Traffic Congestion By Using Queuing Theory	Setting up the M/M/1 queuing model, analyses the traffic intensity of Palasia intersection (Indore city India)	Queuing theory models effectively reduce traffic congestion, improving flow in urban and highway systems.	Queuing theory-based solutions to reduce traffic congestion.
Nadales et al. (2023)	Safe Optimal Vessel Planning on Natural Inland Waterways.	To propose a two-step solution to optimize the time needed for vessels to complete their journey through the waterway.	Developed planning tools for safer vessel navigation, minimising risks and delays in inland waterways.	Optimal vessel planning tools for safer inland waterway navigation.
Nallaperuma et al. (2019)	Online Incremental Machine Learning Platform for	To propose an expansive smart traffic management platform (STMP) based on the unsupervised online incremental machine Learning	Machine learning-based traffic management platforms improve real-time decision-	Machine learning-driven smart traffic management platforms.

	Big Data-Driven Smart Traffic Management		making and traffic flow.	
Prokudin et al. (2022)	Optimising unbalanced freight deliveries in transportation Networks.	To report a comparative analysis of the known methods for reducing open transportation problems to a balanced form in order to further optimise freight traffic based on them	Proposed algorithms to optimise freight deliveries across networks, reducing inefficiencies.	Optimisation algorithms for unbalanced freight deliveries in transport networks.
Patil. (2022)	Deep Learning in Traffic Flow Control and Prediction for Traffic Management.	The aim is to explore the increasing applications of deep learning in traffic management systems, with a focus on traffic prediction, object detection and recognition, autonomous vehicles, traffic flow optimisation, and parking management.	Deep learning models enhance traffic flow, reduce congestion and enhance overall traffic management.	The findings suggest that deep learning models can accurately predict traffic patterns, enabling traffic managers to anticipate congestion and adjust traffic signal timings accordingly

Shmatko et al. (2021)	Modelling a Logistics Hub Using the Digital Footprint Method—The Implication for Open Innovation Engineering.	The study aims to examine the optimisation of the technology of a distribution centre as the base node of a third-party logistics network operator.	The digital footprint method improves logistics hub modelling, increasing efficiency in port and logistics operations.	Results of calculations carried out using a computer according to the proposed algorithm
Wang et al. (2020)	Traffic flow prediction via spatial temporal graph neural network.	To propose a novel spatial temporal graph neural network for traffic flow prediction, which can comprehensively capture spatial and temporal patterns	Spatial-temporal neural networks effectively predict traffic flow, improving management decisions.	Novel spatial-temporal graph neural networks for traffic flow prediction.
Yu et al. (2022)	Ship path optimisation that accounts for geographical traffic characteristics to increase maritime port safety	The paper aims to extend the application of geographical theory and methodology in unmanned ship path optimisation.	Geographical traffic-aware ship path optimisation increases safety and efficiency in maritime ports.	Ship path optimisation methods incorporating geographical traffic characteristics for safer port operations.

Zubkov et al. (2019)	Capacity and traffic management on a heavy-traffic railway line	The purpose of the study is to master the growing volume of traffic and achieve efficiency in operational work	Traffic management models for railway lines reduced congestion and enhanced capacity utilisation.	Traffic management models for optimising heavy-traffic railway operations.
Prokudin et al. (2022)	Logistics of freight transportation and customs service in international transportation	The Paper aims to analyse and optimize the logistics of cargo transportation and customs services for Ukraine under martial law	The study proposes practical measures to harmonize Ukraine's transport and customs logistics practices with European standards, including digitising customs	The study identifies that adopting European customs and logistics standards could reduce costs and delays in international transportation for Ukraine
Yau et al. (2020)	Towards Smart Port Infrastructures: Enhancing Port Activities Using	This article aims to offer a review of the research literature on smart ports, including Internet of Things platform,	The article proposes the exploration of ICT tools such as IoT, cold	It asserts that a stronger focus on ICT in ports could reduce emissions,

	Information and Communications Technology	greenhouse gases emission reduction, energy efficiency enhancement, and so on	ironing, renewable energy, AIS data, and automation— for smart vessel, container, and port management.	energy use, and costs while improving process accuracy and port sustainability.
Sliwczynski (2020)	Value of ICT Integration Model of e-Booking System and Intelligent Truck Traffic Management System in the Sea Port of TEN-T Corridor	The study aims to address the systematic growth of cargo traffic in the TEN-T corridor and European Sea Ports, considering both current port terminals and those planned under development strategies.	ICT integration model improves truck traffic management in seaports, reducing congestion.	The findings indicate that these congestion issues impact cross-border road freight, global maritime supply chains, and international rail freight
Raptis et al. (2019)	Data Management in Industry 4.0: State of the Art and Open Challenges.	This study aims to explore the role of data management in the setting of Industry 4.0 through examining advancements in interconnected industrial settings.	The authors examine data-enabling technologies, particularly those driving cyber-physical convergence (such as digital twins and advanced	Key findings suggest that Industry 4.0 requires improved data management techniques for seamless cyber-physical integration, encompassing

			industrial IoT) within the manufacturing sector.	critical aspects such as real-time data processing, data distribution, and security.
Oskarbski et al. (2019)	Use of data from satellite navigation system in operational and strategic management of transport in cities.	The aim is to explore the use of GPS data to support traffic modelling and management systems for cities.	The intervention involves implementing GPS-based data within Intelligent Transportation Systems (ITS) to facilitate several key applications	The use of GPS data within ITS demonstrates several benefits such as enhanced traffic modelling.
Nadi et al. (2021)	Short-term prediction of outbound truck traffic from the exchange of information in logistics hubs: A case study for the port of Rotterdam	The paper aims to develop a model that predicts short-term changes in truck volumes, generated from major container terminals in maritime port.	The predictive model achieved high accuracy, with a reported 96% success rate on out-of-sample data.	The findings suggest that integrating PCS data into traffic prediction models could enhance efficiency and reliability in managing truck traffic at major freight hubs.

Lehmacher et al. (2022)	Reducing port city congestion through data analysis, simulation, and artificial intelligence to improve the well-being of citizens.	The study aims to reduce congestion and greenhouse gas emissions in port cities, using data analysis, simulation, and artificial intelligence (AI) to optimise traffic flow.	The study demonstrates that AI-based systems, when applied to traffic data, can predict and manage port-related congestion more effectively, reducing GHG emissions and enhancing the quality of life for city residents.	The primary intervention explored involves utilising artificial intelligence, machine learning, and simulation techniques to reduce congestion and emissions.
Lee et al. (2019)	A visual analytics system for exploring, monitoring, and forecasting road traffic congestion.	The study aims to develop an interactive visual analytics system for exploring, monitoring, and forecasting road traffic congestion.	The system uses the Long Short-Term Memory (LSTM) model to predict traffic congestion and introduces visualizations, like Volume Speed Rivers (VSRivers).	The intervention consists of a Visual Analytics System specifically designed for traffic congestion monitoring and forecasting.
Hargroves et al. (2021)	Compare and contrast of options to collect freight vehicle	The aim of this study is to investigate various options for collecting data from freight vehicles and	The study compares various technologies for	The research highlights that linking data from freight

	data in order to inform traffic management systems.	linking this data with traffic management systems to enhance traffic flow and reduce congestion for freight operators.	tracking freight vehicles such as GPS Trackers, RFID tags and Readers	vehicles with traffic management systems can reduce congestion. .
Bessid et al. (2020)	Smart ports design features analysis: a systematic literature review	The study aims to highlight the concept of "Smart Ports," model the structure of a smart port by defining its core activities and identify the critical elements necessary for successful operations within a smart port.	The study suggests two main research directions. Developing a smart port model, Reducing transfer times between storage locations and container berths	The literature review identified several essential components for a smart port system, including the Internet of Things (IoT), Big Data, sensors, RFID, and other advanced information systems.
Barden and Ernfors (2024)	Report Roadmap Digitalisation of the Road Transport System Version 2024	Roadmap for the digitalisation of road transport systems	Proposed digitalisation roadmap improves management of road transport systems,	Roadmap for digitalisation in managing road transport systems.

			enhancing traffic flow.	
Dalaklis et al. (2022)	The port of Gothenburg under the influence of the fourth stage of the industrial revolution: Implementing a wide portfolio of digital tools to optimise the conduct of operations.	The study aims to explore the digital transformation at the Port of Gothenburg and how it leverages Fourth Industrial Revolution (4IR) technologies to optimize operations and advance sustainable development.	The port has launched a digital platform linking stakeholders such as shipping companies, freight forwarders, and rail operators, enabling coordinated and efficient operations within the port area.	The digital initiatives implemented at the Port of Gothenburg have led to significant optimization of port operations and alignment with sustainable development goals.
Rugved Chavan et al. (2022)	Comprehensive review on intelligent traffic management system in India.	To explore various Intelligent Traffic Management Systems (ITMS) for Indian traffic scenarios using technologies like IoT, AI, and RFID, and propose a	ITMS has the potential to alleviate traffic jams and economic setbacks while enhancing safety; however,	Proposes an IT management system incorporating sensors and RFID technology along, with

		scalable, cost-effective solution	it encounters obstacles such, as constraints and the requirement for real time data processing in India's context.	machine learning and cloud computing is being suggested to enhance the prioritization of emergency vehicles and automate fines while regulating signals in response to live traffic data, in India; this system can be customized for emerging countries as well.
Chen, Ioannou & Dessouky (2021)	Mixed freight dynamic routing using a co-simulation optimization approach.	The aim is to develop and evaluate a centrally coordinated dynamic routing system for a mixed fleet of diesel and electric trucks using a co-simulation optimization approach.	A centrally coordinated routing system can reduce emissions and improve load balancing for mixed fleets. realistic routing decisions.	The system uses a technique that simulates layers to adjust the distribution of cargo efficiently while taking into consideration

				the battery range and charging duration of electric trucks. It strategically plans routes to cut down expenses and lower emissions.
Zong-Gan Chen et al., 2022	Evolutionary computation for intelligent transportation in smart cities: a survey.	To review the application of evolutionary computation (EC) for intelligent transportation in smart cities using a two-layer taxonomy.	Evolutionary computing algorithms are adept at tackling optimisation issues in cities intelligent transportation systems by handling extensive and ever changing multi objective challenges effectively.	Proposed a two-layer taxonomy for classifying studies by transportation mode (land, air, sea) and perspective (government, business, citizen). Discussed future research directions, including using machine learning to improve EC algorithm efficiency.

Shuai Hua and David C. Anastasiu (2019)	Effective vehicle tracking algorithm for smart traffic networks.	To develop an efficient vehicle tracking algorithm for smart traffic networks using a track-by-detection paradigm.	The proposed HIOU tracker achieved high tracking performance and speed.	Developed the HIOU tracker, an improvement of the IOU tracker, which uses historical tracking data and balances efficiency and effectiveness in vehicle tracking.
Yang et al. (2018)	Truck appointment at container terminals: Status and perspectives.	The Aim is to review and analyse truck appointment systems (TAS) at container terminals, focusing on congestion, emissions, and operational efficiency.	Truck Appointment System improves operational efficiency and environmental trade-offs.	Proposed future directions: new appointment algorithms, truck appointment flow time under feedback mechanisms, and multi-agent coordinated scheduling.
Muhammad Arif Isham et al. (2022)	Traffic congestion integrated system design development.	To design and develop a smart traffic light system that adjusts light timings based on real-time traffic conditions using AI and IoT technologies.	The study developed a smart traffic system that uses sensors to detect congestion and adjusts green light duration	AI-driven traffic light system integrated with IoT sensors to detect traffic density. The system uses a

			for congested lanes. The system also integrates a mobile app to provide real-time traffic monitoring.	mobile app for traffic monitoring and short message notifications to road users.
Mohamed Zaire Iyoob; van Niekerk (2021)	Caudus: an optimisation model to reducing port traffic congestion.	To develop a smart queue system (CAUDUS) that utilises optimisation algorithms to manage and reduce traffic congestion in port precincts.	The study identifies operational inefficiencies as a significant contributor to	CAUDUS system employs optimisation algorithms to enhance the management of port traffic congestion, focusing on equipment performance, queue thresholds, and capacity to alleviate traffic delays.
Kashinath et al. (2021)	Review of data fusion methods for real-time and multi-sensor traffic flow analysis.	The aim is to review Data Fusion (DF) methods used for real-time and multi-sensor traffic flow analysis (TFA).	The paper identifies significant improvements in Intelligent Transportation Systems (ITS)	The implementation of Data Fusion methods in traffic flow analysis to facilitate real-time processing

			through DF methods.	and improve ITS through better data integration and utilization.
Kuftinova et al. (2022)	Data fabric as an effective method of data management in traffic and road systems.	The Aim is to explore the principles of Data Fabric technology in the context of traffic and road systems and its implications for data management.	It discusses the importance of a centralized data store for processing various types of data (structured, unstructured) and highlights the role of machine learning in optimising data usage.	Development of a data management framework incorporating machine learning and cloud technologies for traffic data analysis.
Laplante, (2018)	"Smarter" Roads and Highways.	The Aim is to explore the potential benefits of IoT technology in road and highway transportation and identify challenges for implementation.	IoT can increase safety, lower maintenance costs, and improve traffic flow. Connected vehicles can warn of hazards and enhance driver satisfaction.	Development of IoT-enabled roads and highways, including connected vehicles, traffic monitoring, and smart infrastructure.

Lau et al. (2022)	Pc-based intelligent traffic monitoring system with real-time analysis for smart cities.	The Aim is to propose a PC-based traffic monitoring system suitable for complex road networks in Hong Kong, focusing on vehicle recognition and real-time data analysis	The proposed system effectively recognises vehicle types and plate numbers, providing valuable data for decision-making regarding traffic policies and congestion management.	Developed a traffic monitoring system that is PC-based and requires no additional infrastructure, utilising a user-friendly dashboard for data visualisation and analysis of traffic data.
Na Li, Haotian Sheng, Pingyao Wang, Yulin Jia, Zaili Yang, Zhihong Jin (2022)	Modeling categorized truck arrivals at ports: big data for traffic prediction.	To propose a deep learning model for accurate truck arrival prediction at container terminals.	The GRU-FCNN model improves prediction accuracy by incorporating factors like vessel information, weekdays, and weather, achieving better results than existing methods for dual, pick-up, and delivery truck arrivals.	The model helps terminal operators better allocate resources, improving operational efficiency, reducing truck turnover time and emissions, and managing congestion effectively.

Liu, Y., Zhang, Q., & Lv, Z. (2021)	Real-time intelligent automatic transportation safety based on big data management.	The Aim of the paper is to analyse the safety and real-time performance of intelligent transportation under big data.	The intelligent transportation model effectively inhibits congestion and provides timely evacuation during traffic congestion.	The study constructs a big data analytics (BDA) prediction platform based on Hadoop and Spark and introduces a deep belief network (DBN) to enhance intelligent transportation safety.
Gunasekaran Manogaran et al. (2022)	Pre-predictive congestion-based data allocation for sixth generation cooperative intelligent transportation systems	To develop a Congestion-aware Pre-predictive Data Allocation (CPPDA) model for traffic data management using 6G technology.	The CPPDA model enhances information gain and response time while reducing outages, communication overhead, and congestion in cooperative intelligent transportation systems (C-ITS).	Implementation of prediction-based learning and 6G communication technologies to enable vehicles to exchange traffic data, thereby improving traffic flow management.

Xu, Bowei et al. (2021)	System dynamics analysis for the governance measures against container port congestion.	The Aim of the paper is to propose a conceptual framework and simulation of congestion governance measures at Shanghai port.	Identified four alternative governance options (Increasing transport infrastructure, Multimodal transport, Smart strategy, and Interconnection) to manage port congestion.	Developed a container port congestion evaluation model; suggested a policy framework to improve coordination and optimisation.
Wang et al. (2020)	Truck traffic flow prediction based on lstm and gru methods with sampled gps data.	The aim of the paper is to propose a novel method for truck traffic flow prediction using sampled GPS data.	The study introduces a two-phase method (data expansion and prediction) using LSTM and GRU neural networks, 'previous expansion.	Implementing a data expansion technique to minimize errors in sampled GPS data and utilising LSTM and GRU for prediction to enhance traffic flow efficiency and safety.
Jabbar et al. (2023)	Blockchain technology for intelligent transportation systems: a systematic literature review	The study aims to develop an Android application for a vehicle tracking system that allows customers to locate available taxis based on their specific	The proposed system utilises GPS technology to track taxis, enabling real-time updates on taxi availability and location.	The application integrates GPS tracking and a server database to facilitate communication between

		requirements, such as location and service time.		customers and taxi drivers.
You et al. (2020)	A generic future mobility sensing system for travel data collection, management, fusion, and visualization.	The Aim is to design and implement a Future Mobility Sensing (FMS) system for holistic collection, management, fusion, and visualization of travel data to enhance understanding of travel behaviour.	The FMS system consists of three platforms: Data Collection, Data Management, and Data Fusion & Visualisation. The system has been successfully deployed in various mobility studies, including an analysis of commercial vehicle parking in Singapore.	The FMS system can be customized for different mobility studies, supporting data collection, fusion, and visualisation to assist.
H. Zhang et al. (2020)	Safecity: toward safe and secured data management design for iot-enabled smart city planning	The aim is to propose a novel architecture, SafeCity, for secure data management in IoT-enabled smart city planning.	The SafeCity framework consists of three layers: a data security layer (using payload-based symmetric encryption), a data	SafeCity provides a three-layer architecture focusing on security (using 128-bit encryption), efficient data loading into

			computational layer (utilising Hadoop), and a decision-making layer for insights.	Hadoop, and customized resource negotiation for effective data computation (dynamic scheduling).