Investigating Landside Congestion at Bulk Cargo Terminals in Forestry Supply Chains: A Role for Information Systems

by

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This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University. Ethics Approval No H0016718.

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3. Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P (2019a). “Understanding the Impact of User Behaviours and Scheduling Parameters on the Effectiveness of a Terminal Appointment System Using Discrete Event Simulation.” In: IFIP International Conference on Advances in Production Management Systems, Springer Berlin Heidelberg
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8. Neagoe, M., Nguyen, H.-O., Taskhiri, M. S., Hvolby H-H and Turner, P "Exploring congestion impact beyond the bulk cargo terminal gate." Logistics 4.0 and Sustainable Supply Chain Management, Proceedings of HICL 2018 (2018): 63-82
9. Neagoe, M., Nguyen, H.-O., Taskhiri, M. S., and Turner, P "Port terminal congestion management. An integrated information systems approach for improving supply chain value." In Proceedings from the Australasian Conference on Information Systems, pp. 1-9. 2017

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Glossary

Term	Explanation
Break-Bulk Cargo	Freight that requires individual handling.
Bulk Cargo	Freight transported in unpackaged large quantities.
Containerised Cargo	Freight transported in intermodal transport units of standardised size.
CoR	Chain of Responsibility. Introduced in October 2018, this legislation aims to ensure supply chain sharing of responsibilities for reducing breaches of heavy vehicle laws and regulations.
Demurrage	Detention of a ship, freight car, or other cargo conveyance during loading or unloading beyond the scheduled time of departure.
Forest Coupe	Area of native or plantation forest managed and designated for timber production.
GBE	Government-Business Enterprise. An Australian Commonwealth entity or Australian Commonwealth company that fulfils three main characteristics: (1) The company's primary purpose is engagement in commercial activities with the private sector; (2) The government controls the company; (3) The company has a legal existence separate from the government.
Hardwood	Wood from dicotyledons trees. Main species used in plantation forestry in Australia are *Eucalyptus globulus* and *Eucalyptus nitens*.
MIS	Managed-Investment Scheme.
NHVR	National Heavy Vehicle Regulator of Australia. Authority established in 2013 to uphold the Heavy Vehicle National Law that applies to vehicles of over 4.5 tones of gross mass.
Softwood	Wood from gymnosperm trees such as conifers. The primary species used in Australian plantation forestry are *Pinus radiata*, *Pinus caribaea*, and *Pinus elliottii.*
Stevedore	Port terminal operating company.
TAS	Terminal Appointment System.
Throughput	Used mainly in a port context, represents the quantity of goods processed by the port during a specified period of time.
Timber	a type of wood that has been processed into beams and planks, a stage in the process of wood production.
VBS	Vehicle Booking System – alternative name for terminal appointment system (TAS) used primarily in Australian and North American marine terminals.

Abstract

This research investigates landside congestion at bulk cargo marine terminals in forestry export supply chains and explores the role of information systems in understanding congestion and mitigating its impacts. Through the conduct of three qualitative case studies supported by quantitative modelling, this research contributes to a more holistic understanding of congestion factors, their interactions, and mechanisms for congestion mitigation at bulk cargo terminals in forestry supply chains.

Contemporary approaches to understanding and mitigating congestion, both in the research literature and in practice, have primarily focused on the supply chain's individual components rather than on how these components interact. These approaches are often disconnected from the underlying factors that contribute to the emergence of congestion in the system as a whole and focus on congestion symptoms and their resolution at pinch-points along the supply chain. Many congestion mitigation approaches prioritise technical solutions that address narrowly defined technical, economic and regulatory metrics. For example, digital tools in the form of terminal appointment systems (Huynh, Smith and Harder, 2016; Schulte et al., 2017) and automation technologies (Heilig and Voß, 2017) are regularly promoted to manage congestion. While these tools are undoubtedly useful, their promotion is often primarily for terminal efficiency or cost considerations (Chang Guan and Liu, 2009), in isolation from other factors that may be equally important. More broadly, evidence supporting infrastructure, technology and regulatory instruments as impacting positively on congestion, are too frequently only measured through narrowly defined metrics at specific points in a supply chain exhibiting congestion. This raises questions relating to what extent positive evaluations of congestion mitigation are partly a consequence of shifting the congestion problem to other parts of the supply chain. This issue has remained under-explored, as have the mechanisms through which congestion mitigation approaches are chosen and how their effects are experienced by various stakeholders involved in bulk cargo supply chains.

Improving understanding of factors contributing to congestion is important, as is a better understanding of the adoption, use and application of information systems as part of approaches to mitigate the effects of congestion. Two of the most influential and highly cited papers in the domain of landside congestion management are empirical investigations (Giuliano & O'Brien, 2007; Morais & Lord, 2006). The issues highlighted by these papers regarding the ineffectiveness of appointment systems and other congestion mitigation methods in practice have been the primary driver for this work. Although these papers are more than a decade old, the extant research literature has, to date, failed to answer the question of how theoretical benefits derived from congestion mitigation be achieved practice. This research provides enhanced insights into factors contributing to congestion and into mechanisms for its mitigation. The research also presents insights into selecting and calibrating mechanisms to enhance their effectiveness for the entire supply chain.

Landside congestion is conceptualised as a 'wicked' problem to sensitise this research to the socio-technical factors and their interactions in forest products export supply chains. 'Wicked' problems as described by Rittel and Webber (1973) are characterised by a plurality of perspectives on the problem, stakeholder objectives and potential problem resolutions. Already research has identified novel technologies such as remote sensing, networked embedded sensors operating in the Internet of Things (IoT) (Scholz *et al.*, 2018), blockchain (Jabbour *et al.*, 2020) artificial intelligence (AI), machine learning and deep learning as well as big data and cloud computing (Müller, Jaeger and Hanewinkel, 2019) are perceived as both disruptors and potential solutions to the many challenges faced by modern supply chains including forestry. However, most research focuses on technical aspects of these technologies and to a lesser extent on understanding of the importance and impact of social and behavioural components. Indeed, whilst there are large numbers of research papers advocating for the use of these novel technologies, few, if any, provide detailed insights into the mechanisms for their implementation or metrics to evaluate their impact on congestion. To address this limitation, this research adopted a participatory design approach to capture the multiple perspectives from the diverse set of supply chain stakeholders grappling with the congestion. More specifically, the participatory design approach used focused on facilitating solution development by participants in ways sensitive to the role of digital tools and techniques along the supply chain (Bødker, Kensing and Simonsen, 2004, 2011).

The methodology adopted in this research involved the conduct of three participatory design case studies. Each case study focused on an Australian bulk-cargo marine terminal and its users' supply chains. The **research strategy** consisted of three stages deploying both qualitative and quantitative data collection and analysis techniques. The three stages were: exploration, design workshops and evaluation. This investigation was underpinned by a subjective ontology and an interpretive epistemology. Using multiple case studies was designed to overcome the perceived shortcomings of a single case concerning generalisability, the causal relations identified (Cavaye, 1996), and the possibility that findings result from case idiosyncrasies (Miles and Huberman, 1994).

In terms of **research design**, Stage 1: Exploration aimed to provide a baseline understanding of the participants' perceptions of congestion factors, implications and potential mitigation mechanisms. During Stage 1: Exploration, qualitative data were collected through 13 site visits and 30 semi-structured interviews. These data were coded using a process drawing on grounded theory principles and led to insights that guided the subsequent stages. Quantitative data consisting of more than 250,000 truck arrival records and over 16,500 truck geo-positioning entries were also collected. These data were analysed in the next stage of the research to prepare the workshops.

Stage 2: Design Workshops aimed to capture the joint understanding of the participants' perceptions, facilitate the alignment of perspectives, and develop a common vocabulary among participants. Furthermore, the workshops included a design component in which participants could develop congestion mitigation approaches for their supply chains. Four workshops involving 25 participants across the three case studies were conducted. The quantitative data were analysed using simulation modelling and exploratory data analysis to improve understanding of the impact of stochastic components on the terminal's operational performance and evaluate the truck unloading operations' sensitivity at the terminal to changes in these stochastic components or the terminal setup. The quantitative data analysis results were

presented during the workshops and directly contributed to a common understanding of options' implications. The qualitative data emerging from this stage were coded using a process drawing on grounded theory principles.

Finally, Stage 3: Evaluation aimed to explore the effectiveness of the participatory design process on the participants' understanding of congestion and where possible, to evaluate the impact of developed and implemented solutions on congestion. It could not be assumed at the outset of the research that the supply chain stakeholders would implement the designs emerging from the workshops. However, when this did occur, the second component of Stage 3: Evaluation aimed to capture the impact of the designs on congestion. Stage 3: Evaluation consisted of 11 semi-structured interviews and approx. 10,000 truck arrival records. Qualitative data from the workshops were also used during Stage 3: Evaluation. This research has been approved by the Human Ethics Research Committee (Tasmania) under ref: H0016718.

The **key findings of this research** pertain to a better, more holistic, understanding of congestion factors, mitigation design alternatives and impact evaluation. The research has also highlighted the utility of a participatory design approach in achieving these results and has explored in detail the role information systems can play in better understanding and mitigating congestion at bulk cargo marine terminals for forest products.

KF-1. Social, technical and behavioural factors and processes pertaining to the terminal, the marine- and landside supply chain interact to contribute to the appearance and severity of landside congestion. Therefore, congestion can be considered an 'emergent' property of intersecting supply chains. As a result, congestion mitigation is often perceived to fall outside individual organisations' responsibility. The factors and processes identified in this research include:

- limited coordination of logistics flows within organisations, and within and between forest products supply chains,
- misaligned incentives within organisations, and within and between forest products supply chains,
- excessive interdependence of operations within supply chains and technical limitations to flexibility,
- infrastructure capacity or performance limitations
- behavioural responses associated with operational disruptions and congestion,
- misinterpretation of performance expectations
- a plurality of perspectives on congestion within and between supply chains;

KF-2. Congestion, particularly with increased recurrence, affects the costs, compliance and fatigue risks of truck operators and creates operational uncertainty and the generation of significant frustration for participants across supply chains. Congestion is not only an operational problem. Failure to conceptualise and respond to congestion as a supply chain problem has consequences for the competitiveness and resilience of individual organisations and supply chains.

KF-3. The participatory design approach utilised in this research enhanced the researcher's and participants' understanding of congestion and facilitated the emergence of contextually relevant congestion mitigation mechanisms. A key component of the participatory design approach was the interplay between the qualitative and quantitative data and analysis. Qualitative techniques permitted identifying aspects pertaining to congestion that do not easily lend themselves to quantification. Quantitative techniques allowed the validation of or challenging of participants' perceptions and beliefs underlying their conventional responses to congestion. An outcome of the approach was that the participants designed and implemented mechanisms to mitigate congestion and initiated the deployment of digital tools to support coordination efforts and also attempted to apply by themselves the same approach in other similar circumstances.

As a result, the congestion factors previously discussed in *KF-1* were identified and congestion was defined as "*An emergent symptom of logistics systems, characterised by higher-than-expected delays, generally manifesting at marine terminals, caused by a plurality of factors and their interactions and a multitude of stakeholders' perspectives and associated individual response behaviours*". Furthermore, the participants designed and implemented mechanisms to mitigate congestion and investigated the deployment of digital tools to support coordination efforts. These were evaluated, and their positive impact on congestion confirmed.

KF-4. Conventional measures for congestion (e.g. average truck turnaround times), used in isolation from other indicators, tend to misrepresent congestion. Performance metrics based solely on average measures may obscure the uncertainty and variability of measurements. Stakeholders may have unrealistic expectations as the average is often confused with the maximum. Congestion mitigation measures aimed at addressing average measures for congestion may, in fact, fail to address congestion even if successful at reducing the average measures.

KF-5. Information systems can contribute to better understanding and mitigation of congestion. Exploratory data analysis and simulation modelling highlighted the congestion-related bottlenecks and helped challenge the participants' assumptions on congestion factors and frequency of occurrence. Furthermore, the simulation scenario analyses helped direct the participants' attention towards designing for the most promising congestion mitigation approaches.

Information sharing supported the supply chain coordination mechanisms designed by participants. Information sharing, both at the operational and tactical levels pertaining to truck and vessel schedules, was instantiated to enhance coordination between the supply chains intersecting at the terminal. In one case study, the participants also commenced the procurement process for a terminal appointment system to facilitate truck arrivals' coordination at the terminal. The initiation of information sharing was partially contingent on addressing information asymmetry between participants and a mutual definition of each party's behavioural responses following information sharing.

KF-6. The participants' perceptions of the expected benefits of digital tools to mitigate congestion were not grounded in evidence or a clear understanding of the

mechanisms through which information technology would address congestion. As a result, the way in which technology was adopted and utilised by users was rarely closely correlated to congestion mitigation. Indeed, there were numerous examples of where individual organisations had justified investment in IT tools by reference to landside congestion management but had not subsequently analysed the data produced by these systems or utilised it to address congestion-related challenges proactively.

These key results have also led to the production of a model for identifying and understanding interactions among factors contributing to congestion and a framework to support holistic responses to congestion mitigation.

Chapter 1 Introduction

1.1 Introduction

This research explores the role of information systems in understanding and mitigating landside congestion in bulk cargo marine terminals for forest products. Information systems are defined as systems that involve social and technical elements interacting through processes and actions that use information, technology, and other resources to produce informational products and services (Checkland, 1988; O'Hara, Watson and Kavan, 1999; Alter, 2008). This chapter is divided in the following sections:

- Section 1.2 describes the context of this research in terms of bulk cargo and forestry supply chains in Australia and road and port congestion management in practice.
- Section 1.3 provides an overview of this research's conceptual framework and introduces the key research literatures underpinning this framework. The research literatures on port-centric supply chains, landside congestion management in marine terminals, wicked problems, participatory design and the role of information systems in organisations and supply chains are discussed.
- Section 1.4 discusses the research problem and research questions.
- Section 1.5 describes the research approach adopted for this research. Multiple case studies utilising a three-stage participatory design approach and deploying qualitative and quantitative data collection and analysis techniques were employed in this research.
- Section 1.6 discusses this thesis's contributions at the conceptual, methodological and substantive levels.
- Section 1.7 provides an overview of the structure of this thesis.
- Section 1.8 provides a summary reflection of this chapter.

1.2 Research Context

Australia exports primarily raw materials, the majority of which are exported in bulk form. Bulk cargo exports typically take place through specialised marine terminals to transfer the goods from land- to sea-based transportation. Australia's large physical distances and sparse regional population distribution means that high-capacity trucks are used to transport bulk commodities. Consequently, road transport is one of the preferred modes of transport.

Forest products exports are the 5th largest Australian raw material bulk export. A large proportion of plantation forest products exports are a subset of bulk cargo export supply chains – with limited volumes exported in containers. There are a relatively limited number of forestry production hubs and, similarly, a limited number of bulk cargo marine terminals for forest products exports, through which a high volume of forest products are transported, almost exclusively by road transport. Ostensibly, forest products export supply chains have a limited complexity. However, they feature a large number of stakeholders, export and processing options.

Congestion is an issue on Australian roads and in the largest Australian ports. Road congestion management approaches tend to focus on infrastructure building and the use of digital tools. Similarly, in container terminals, infrastructure construction and the use of digital tools – particularly vehicle booking systems – are prevalent. Although bulk cargo terminals share several characteristics with container terminals, there is limited evidence of the use of digital tools in managing congestion in bulk cargo marine terminals.

Importantly, this research took place during one of the worst bushfire seasons in Australia's recent history (Guardian, 2020) and the COVID-19 pandemic. It was likely that these events would affect the outcomes of this research.

The contextual factors discussed above can have several implications on this research: The limited number of bulk cargo marine terminals appears to lend itself to a case study rather than a quantitative exploration; The similarities between forest products and other bulk cargo export supply chains may entail that the approach utilised in this research could be useful in other bulk cargo contexts; similarly, some findings of this research can sensitise researchers working in other types of bulk cargo supply chains.

The next section discusses the relevant research literatures for this research. These include the research literature on port-centric supply chains, landside congestion in marine terminals and wicked problems, participatory design and information systems.

1.3 Research Background

1.3.1 Port-Centric Supply Chains

In a global trade context, supply chains compete (Christopher, Peck and Towill, 2006). Maritime terminals sit at the intersection of multiple supply chains that otherwise operate reasonably independently of one another. This unique position can create a series of challenges, including that of landside congestion. The consequences of landside congestion are experienced by the terminal operator, where congestion generally emerges and the terminal users' supply chains. Terminal operators experience peaks in demand that exceeds their capacity, leading to processing delays (Huynh, Smith and Harder, 2016). Transporters and logistics service providers experience increased costs, waiting times, service time uncertainty and lost transport opportunities (Kockelman, 2004; Meersman, Voorde and Vanelslander, 2012; Davies and Kieran, 2015), leading to increased supply chain costs (Loh and Thai, 2015), ultimately increasing supply chain uncertainty and decreasing resilience and competitiveness.

1.3.2 Landside Logistics, Congestion and its Management at Marine Terminals

Conventional approaches to understanding and mitigating congestion, both in the research literature and in practice, tend to focus on the supply chain elements. The landside operations research (e.g. Rönnqvist *et al.*, 2015), maritime logistics (e.g. Christiansen *et al.*, 2013), and terminal congestion management (e.g. Li *et al.*, 2018; Pratap *et al.*, 2018) literature typically focus on problems within the disciplinary boundaries, often overlooking the external causal factors and consequences. Landside congestion management approaches include technology, infrastructure (Maguire *et al.*, 2010) and policy instruments (Giuliano and O'Brien, 2007).

Terminal operators or regulatory bodies typically undertake congestion management. However, there appears to be a limited understanding of the factors that contribute to the appearance of congestion, as supply chain stakeholders are rarely involved in mitigation efforts (Van Der Horst and De Langen, 2008; Jaffee, 2016). Similarly, there is limited understanding of the trade-offs and impacts amongst different congestion mitigation approaches. Thus, whilst some landside congestion management approaches have succeeded in reducing truck waiting times (Giuliano et al., 2008; Davies and Kieran, 2015), it is unclear whether the issue has been addressed or simply obscured in other parts of the chain where it can continue to undermine the terminal's and supply chains' resilience and competitive advantage.

1.3.3 Wicked Problems, Participatory Design and Information Systems

Landside congestion, therefore, exhibits some of the features of 'wicked' problems such as multiple stakeholders with often conflicting perspectives, interests as well as a diverse set of potential approaches to address the issue. 'Wicked' problems (Rittel and Webber, 1973) are characterised by a plurality of perspectives on the problem, stakeholder objectives and potential problem resolutions. Formulating the problem is, in fact, a significant challenge in itself, as the initial problem may be a symptom of another problem (Rittel and Webber, 1973).

The social, behavioural and technical factors that interact in bulk cargo marine terminals for forest products add further complexity to the in-depth exploration of congestion requiring a suite of qualitative and quantitative techniques to unpack this complexity. In this context, participatory design is an approach aimed at aligning perspectives, facilitating mutual understanding amongst participants and conflict resolution through building trust and compromise (Bratteteig *et al.*, 2012; Kanstrup and Bertelsen, 2013). The focus on design means that contextually grounded and negotiate solutions can also emerge from the process. Participatory design has been predominantly used in recent years in information systems design and implementation (Pihkala and Karasti, 2016; Østergaard, Simonsen and Karasti, 2018; Tang *et al.*, 2018) and provides a potentially useful framework for grappling with the complexity of the problem.

Information systems' potential to facilitate communication and task automation and improve information quality and real-time visibility is well documented in the research literature (Fawcett *et al.*, 2011; Heilig and Voß, 2017; Ruel, Ouabouch and Shaaban, 2017). However, this potential has failed to consistently translate to increased efficiency and competitive advantage as some researchers have suggested (Forslund, 2007; Sezen, 2008). This holds true also for landside congestion management approaches based on information systems such as terminal appointment systems and gate automation technologies. Consequently, understanding the contributing factors to congestion and the aspects conducive to using and applying information and digital technology may provide further insights into the mechanisms that can be used to mitigate congestion.

The next section encapsulates the research problem at conceptual, methodological and substantive levels and the resulting research questions of this research.

1.4 Research Problem and Questions

The analysis of research literatures discussed above highlights a series of gaps at a conceptual, methodological and substantive level. At a theoretical level, the research in the logistics space tends to be segmented into discrete research foci. These foci can centre either on different organisation types (e.g. terminal operators) or transport modes (e.g. land- or sea-based). The problems defined within these research foci are often addressed with an efficiency or cost focus (Andersson *et al.*, 2010; Ambrosino and Caballini, 2015; Gansterer and Hartl, 2018). Some researchers have also subscribed to more holistic perspectives which recognise that logistics challenges can be affected by other logistics operations (Van der Horst and De Langen, 2018) or supply chain elements (Andersson, 2011). Holistic approaches recognise the existence and potential impact of inter-relationships amongst logistics and supply chain elements.

The importance of a holistic perspective in understanding inter-relationships amongst logistics and supply chain elements and their impact is highlighted in the research literature in two ways: from a problem structuring view, the definitions of problems formulated within a research focus may be artificially bounded and not shared across organisations. This may, in turn, affect the perceived courses of action available to address the problem. Furthermore, the consequences of implementing solutions may not be fully captured, particularly those consequences occurring beyond the boundaries of the problem formulation (Rosenhead, 2013; Smith and Shaw, 2019); from an integration view, approaches considering multiple elements of a supply chain and their inter-relationships can reduce uncertainty (Huang, Yen and Liu, 2014), enhance performance, competitive advantage (Schoenherr and Swink, 2012).

The research on the role of information systems (IS) in logistics and supply chain has tended to focus on the organisational level. This focus is primarily supported by the resource-based view (RBV). Consequently, IS are considered communication and automatization enabler and ultimately drivers for increased organisational efficiency and competitive advantage (van Baalen, Zuidwijk and van Nunen, 2008; Heilig and Voß, 2017). Significant focus has been placed in supply chain and logistics research in understanding the role digital tools can play. In these research domains, empirical investigations which explore the use of digital tools in practice are relatively rare. Often, however, the digital tools' attributes are not considered in relation to the issues they are expected to address. The research literature on information sharing provides an extensive description of the antecedents, barriers, dimensions and outcomes of implementing information sharing. However, it remains unclear whether and how understanding existing information sharing practices can help initiate new information sharing or maintain the continuity of existing practices.

The challenges described above also manifest in landside congestion management at marine terminals. Contemporary approaches to understanding and mitigating congestion, both in the research literature and in practice, have primarily focused on the supply chain's individual components rather than on how these components interact. As a result, these approaches are often disconnected from an awareness of many of the underlying factors contributing to the emergence of congestion. Furthermore, many congestion mitigation approaches tend to prioritise technical solutions that address narrowly defined technical, economic and regulatory metrics. For example, digital tools in the form of terminal appointment systems (Huynh, Smith and Harder, 2016; Schulte et al., 2017) and automation technologies (Heilig and Voß, 2017) are one of the preferred landside congestion management approaches. The use of digital tools for landside congestion management seems often motivated by terminal efficiency or cost considerations (Chang Guan and Liu, 2009) rather than understanding the tools' roles in mitigating congestion. Evidence in the research literature and practice points towards how infrastructure, technology, and regulatory instruments can impact congestion, as measured through narrowly defined metrics, at individual points in the supply chain. However, the extent to which this may be partly a consequence of shifting the problem to other parts of the supply chain remains unclear, as does the mechanism through which congestion mitigation approaches are chosen. A better understanding of the factors contributing to the appearance of congestion and of suitable mitigation mechanisms may help improve the effectiveness of approaches aimed at managing congestion.

At a methodological level, the approaches most frequently used in the research literature analysed tend to be quantitative, centred on surveys or analytical modelling. These approaches effectively improve understanding of existing issues and challenges and illustrate potential optimal outcomes. However, they provide limited guidance on how mechanisms or digital tools can be implemented to address the challenges identified and achieve modelled optimal outcomes. Furthermore, the objective assumptions of quantitative approaches may limit the variety of perspectives adopted in analysing a problem. Participatory design is an approach that can facilitate improved understanding of a problem and the design and implementation of contextually-relevant solutions, including digital tools. Participatory design has been previously used to develop and implement IS in healthcare (Østergaard, Simonsen and Karasti, 2018; Tang *et al.*, 2018) or enterprise resource planning systems (Pries-Heje and Dittrich, 2009). Although promising, participatory design has yet to be used in the context of landside congestion management.

At a substantive level, an overwhelming proportion of research in landside congestion management has been focused on container terminals (Chen and Jiang, 2016; Torkjazi, Huynh and Shiri, 2018). In Australia, landside congestion management has received little attention even in container terminals (e.g. Davies and Kieran, 2015). The research on landside congestion management in bulk cargo marine terminals is limited and, to date, no research has investigated landside congestion management in bulk marine terminals for forest products.

The following research questions were therefore formulated to address the research problems identified:

RQ-1. What congestion factors, their interrelationships, and implications can be identified and understood?

RQ-2. How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?

RQ-3. What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?

The next section discusses the research approach adopted in this investigation to answer the research questions.

1.5 Research Approach

The methodology adopted in this research was a multiple case studies participatory design approach. The research strategy consisted of three stages which included both qualitative and quantitative data collection and analysis techniques: exploration, design workshops and evaluation. This investigation was underpinned by a subjective ontology and an interpretive epistemology. The participatory design approach was applied to three case studies centre on Australian bulk-cargo marine terminals and their users' supply chains. Multiple case studies can partially overcome the perceived shortcomings of a single case concerning its generalisability, the causal relations identified (Cavaye, 1996), and the possibility that findings result from case idiosyncrasies (Miles and Huberman, 1994).

In terms of research design, Stage 1: Exploration aimed to provide a baseline understanding of the participants' perceptions of congestion factors and consequences and potential mitigation mechanisms. During Stage 1: Exploration qualitative data were collected through 13 site visits and 30 semi-structured interviews. These data were analysed using a coding process drawing on grounded theory principles and led to insights that guided the subsequent research stages.

Stage 2: Design Workshops aimed to capture the joint understanding of the participants' perceptions and facilitate the alignment of perspectives and the development of a common vocabulary amongst participants. Furthermore, the workshops included a design component in which participants, using the common vocabulary, could develop congestion mitigation approaches for their supply chains. Four design workshops involving 25 participants across the 3 case studies were conducted. Quantitative data consisting of more than 250,000 truck arrival records and around 16,500 truck geo-positioning entries were also collected. The quantitative data were analysed using simulation modelling and exploratory data analysis. The results of the quantitative data analysis were discussed during the workshops. The qualitative data emerging from this stage were analysed using a coding process drawing on grounded theory principles.

Finally, Stage 3: Evaluation aimed to explore the effectiveness of the participatory design approach on the participants' understanding of congestion. It was not clear from the onset whether the designs emerging from the workshops would be implemented. If this were the case, the second component of Stage 3: Evaluation aimed to capture the impact of the designs on congestion. Stage 3: Evaluation consisted of 11 semi-structured interviews and more than 10,000 truck arrival records. Qualitative data from the workshops was also used during Stage 3: Evaluation. The quantitative data were analysed using exploratory data analysis while the qualitative data were analysed using the coding process drawing on grounded theory principles.

The next section presents this research's contributions at the conceptual, methodological and substantive levels.

1.6 Research Contributions

This research has generated a series of contributions to the current research literature at, substantive, methodological and conceptual level.

1.6.1 Substantive

At a **substantive** level, this research provides a detailed, in-depth exploration of three case studies centred on bulk cargo marine terminals for forest products and their associated supply chains experiencing landside congestion. For each of the case studies included, the researcher provided extensive data analysis and recommendations report to organisations involved in the supply chain. A discrete-event simulation model of a bulk cargo marine terminal was also constructed and used to evaluate the impact of different congestion mitigation scenarios. In one case, the report as a guide for the participants to improving operations and manage congestion.

This research has also found that the implications of congestion can be felt at a supply chain level. Congestion can affect the competitiveness of the supply chains against other, similar chains. Similarly, this research has also found that congestion can affect the supply chain's resilience through ongoing system strain.

The role of information systems in congestion mitigation was also empirically illustrated. Thus, information sharing that supported the coordination mechanisms instantiated by the participants was an important factor in reducing truck turnaround times and congestion. This research found that the initiation of information sharing was partially contingent on the level of information asymmetry and provided evidence that a reduction in asymmetry can facilitate the emergence of new information sharing mechanisms. Furthermore, the establishment and communication of behavioural expectations was an essential factor in supporting information sharing.

This research also provided a detailed description of the Australian forest products export supply chain and identified aspects that should be considered in the research design. These include the regulatory framework under which the supply chain operates, the supply chain structure and competitors.

1.6.2 Methodological

At a **methodological** level, this research has shown the usefulness of the participator design approach in better understanding congestion, mitigation approaches, and information systems' role in this context. This research has contributed to the research literature investigating congestion and its management through a methodology that broadens the investigation scope to include a large proportion of the supply chain and explores the phenomena using qualitative and quantitative data collection and analysis techniques. The methodology employed effectively generated mutual understanding and a common vocabulary between participants in the case studies, and ultimately led to the emergence and adoption of congestion mitigation designs.

In synthesizing the insights developed in this research, a framework for participatory mitigation of landside congestion emerged. This framework can be used as a sensitising device for researchers on approaching congestion mitigation in bulk cargo marine terminals. This framework also highlights the links between the congestion factors and the mitigation mechanisms and presents an approach for developing contextually-adapted mitigation mechanisms. Two of the most influential and highly cited papers in the domain of landside congestion management are empirical investigations (Giuliano & O'Brien, 2007; Morais & Lord, 2006). The issues highlighted by these papers regarding the ineffectiveness of appointment systems and other congestion mitigation methods in practice have been the primary driver for this work. Although these papers are more than a decade old, the extant research literature has, to date, failed to answer the question of how theoretical benefits derived from congestion mitigation be achieved practice. The participatory mitigation of landside congestion framework developed in this research represents this work's contribution to this body of knowledge.

The breadth of the qualitative data collection and the coding process drawing on the principles of grounded theory of the qualitative data proved useful in revealing novel insights regarding congestion. The data collection included a range of stakeholders involved in the supply chain. Thus, the analysis revealed novel insights regarding the range of congestion factors that pertained to the terminal and the supply chains. Interestingly, the analysis also revealed differences in perspectives amongst participants regarding congestion factors and mitigation strategies.

The use of qualitative and quantitative data collection and analysis allowed for triangulation of results and highlighted a series of aspects with regards to congestion: differences between the importance participants attributed to terminal infrastructure concerning congestion and the impact it had on congestion; differences between the importance attributed by participants to coordination and its impact on congestion and; differences in expectations and interpretation of measures of congestion.

The discrete-event simulation model took advantage of novel data sources and model capabilities to generate relevant insights for the participants. Thus, the simulation model was constructed using overlapping geo-positioning data from trucks and truck arrival data spanning more than three months. The resulting model was a relatively robust and accurate representation of terminal operations. Furthermore, the model was used to evaluate the impact of various congestion factors and the effectiveness of multiple congestion mitigation approaches.

Importantly, the workshops that included supply chain participants were useful in generating mutual understanding and facilitated the development of situated approaches to mitigate congestion. The participants developed coordination mechanisms supported by information sharing, which were subsequently implemented and partially mitigated congestion. Furthermore, partially due to the simulation modelling results, the terminal operator, in one case study, with the participants' support, commenced the procurement process for a terminal appointment system solution.

The participatory design approach used in this research was a useful tool to investigate a phenomenon beyond organisational boundaries to generate a holistic understanding both for the researcher and the participants themselves and provided an environment conducive to the emergence of designs aimed at addressing the phenomenon.

1.6.3 Conceptual

At a **conceptual** level, this research has revealed the usefulness of a holistic, supply chain perspective for better understanding the social and technical factors conducive to the appearance of congestion and the consequences this phenomenon has on the affected organisations and individuals. This research also explores the role of information systems in relation to congestion factors.

This research contributed to the research literature by highlighting that a more holistic approach, integrating the sea-, terminal and landside elements of the chain can reveal additional aspects relevant to congestion. A model of congestion factors interacting at the different levels of analysis that emerged from aggregating the findings of this applied research was developed. The model categorises factors into behavioural, social and technical across the three different levels of analysis, from individuals within organisations, organisations within supply chains and organisations between supply chains converging at the same facility. The congestion factors identified in this research were: limited coordination of logistics activities, interdependence with other supply chain operations, misaligned incentives, inadequate terminal infrastructure, operational disruptions and lack of supply chain flexibility. Importantly, this research has also highlighted that across the range of supply chain stakeholders, perceptions on congestion and contributing factors vary significantly. Therefore, this research questions the assumption that landside congestion in marine terminals is a terminal problem that falls under the responsibility of terminal operators.

This research has contributed to the research literature by defining congestion as "*An emergent symptom of logistics systems, characterised by higher-than-expected delays, generally manifesting at marine terminals, caused by a plurality of factors and their interactions and a multitude of stakeholders' perspectives and associated individual response behaviours*". This definition complements existing definitions of congestion that are less useful in understanding and exploring the phenomenon of congestion.

The importance of understanding the congestion factors and aligning the congestion mitigation approaches, particularly those related to digital tools was also highlighted in this research. The effectiveness of various congestion mitigation methods was compared using simulation modelling. This comparison highlighted that additional infrastructure was often less effective than improved coordination using appointment systems. This research has also provided evidence that the appointment system's effectiveness is related to the congestion factor it helps mitigate. Thus, in this research, a primary congestion factor was the limited coordination which can be effectively addressed using an appointment system. The simulation model has also provided evidence that automation technology can improve operational efficiency and reduce truck turnaround times but may have a limited impact on waiting times and therefore, congestion.

The next section presents a summary of each chapter.

1.7 Chapter Summary

This section provides a brief overview of the structure of this thesis.

1.7.1 Chapter 2 - Research Context

Chapter 2 discusses the context within which the research was conducted. The local, regional and national context concerning supply chains, ports, forestry, and congestion management can affect individuals' and organisations' behaviours within supply chains.

1.7.2 Chapter 3 - Literature Review

Chapter 3 discusses the key research literatures in relation to the domains relevant to this research: port-centric supply chains, landside congestion management, '*wicked*' problems, structuring methods and the role of information systems in understanding and addressing these issues.

1.7.3 Chapter 4 - Methodology

Chapter 4 presents the multiple case studies participatory design approach employed in this research. For each case, a participatory design methodology was used in 3 stages: exploration, design workshops and evaluation. Qualitative data was collected throughout the three stages and analysed using a coding process drawing on grounded theory principles. Quantitative data was collected in Stage 1: Exploration and Stage 3: Evaluation and analysed using exploratory data analysis and simulation modelling.

1.7.4 Chapter 5 - Data Analysis and Results

Chapter 5 discusses the data analysis process results in this research. The qualitative and quantitative data collected in each of the three-stage of the research was analysed using a coding process drawing on the principles of grounded theory, simulation modelling and exploratory data analysis. Following each stage of the research, preliminary results were drawn, which guided the subsequent stages.

1.7.5 Chapter 6 - Interpretation and Discussion of Findings

Chapter 6 presents the six key findings emerging from the analysis and interpretation of the data across this research's three stages. The key findings are discussed and interpreted in this chapter concerning the extant research literature and the research questions.

1.7.6 Chapter 7 - Conclusions

Chapter 7 presents the conclusions of this chapter.

1.8 Conclusions

This chapter has provided a brief background of this research.

The research problem with respect to congestion, its management, and information systems' role in understanding and mitigating congestion was explored in this chapter. To answer the emerging research questions, a multiple case studies participatory design approach was employed. The approach was structured in three stages – exploration, design workshops and evaluation – and used qualitative and quantitative data collection and analysis techniques. The approach was applied to three case studies centred on bulk cargo marine terminals for forest products and their associated supply chains. This research made several contributions to the body of knowledge at a substantive, methodological and conceptual levels. Substantively, this research provided a detailed, in-depth exploration of three case studies centred on bulk cargo marine terminals for forest products and their associated supply chains experiencing landside congestion. Methodologically, this research highlighted the usefulness of the multiple case studies participatory design approach to better understand, define, and measure congestion. Importantly, the participatory design approach's usefulness in supporting the development and implementation of situated congestion mitigation mechanisms was also highlighted. At a conceptual level, this research explored socio-technical congestion factors and their interactions, congestion approaches and the role of information systems in understanding and aligning the congestion factors with mitigation approaches.

The next chapter discusses the context within which the research was conducted. Three aspects are considered from a contextual perspective: the Australian bulk cargo export supply chains, Australian plantation forestry export supply chains and congestion management initiatives.

Chapter 2 Research Context

2.1 Introduction

This chapter discusses the context within which the research was conducted. Three aspects are considered relevant from a contextual perspective: the Australian bulk cargo export supply chains, Australian plantation forestry export supply chains and congestion management initiatives. The structure of this chapter is:

- Section 2.2 discusses the main features of Australian bulk cargo export supply chain. Raw materials in bulk form are Australia's largest cargo exports. Exports of bulk cargoes typically take place through specialised marine terminals in transferring goods from land- to sea-based transportation. Australia's large physical distances and sparse regional population distribution make road transport a preferred transport mode. High-capacity transport equipment is used in such tasks. This situation brings with it challenges in terms of legislation compliance and fatigue management.
- Section 2.3 presents the key aspects of Australian forest products export supply chains. Forest products exports are the 5th largest Australian raw material bulk export. The majority of forest exports products are sourced from forest plantations and exported through a limited number of dedicated bulk cargo marine terminals. These terminals handle large volumes of forest products. Cargoes are delivered to these terminals almost exclusively by road transport. In this research, the main forest products considered are logs and wood chips. These products represent the majority of plantation forest exports in bulk.
- Section 2.4 discusses identified or implemented approaches to mitigate Road traffic and port congestion in Australia. Congestion is an issue on Australian roads and in the largest Australian ports. Most road traffic and port congestion management approaches tend to focus on infrastructure building and the use of digital tools. In ports, and particularly in container terminals, the use of vehicle booking systems (VBS) is prevalent. Congestion management approaches used in other settings may be adapted for bulk cargo marine terminals.
- Section 2.5 presents the conclusions of this chapter.

2.2 Bulk Cargo Export Supply Chains

Raw materials are one of Australia's main physical goods exports. Raw materials are usually transported in bulk and are typically exported through a relatively limited number of port facilities in proximity of extraction, refining or harvesting sites. Forest products exports are mostly done in bulk. Importantly, while forest products export supply chains contain relatively few processing stages, they derive significant complexity from their organisational setup and fragmentation.

All three transport modalities are utilised for bulk cargo in Australia, road, rail and barge. The Australian geography is characterised by vast distances between population centres and relatively dispersed industries. Rail transport is therefore available and viable in populous areas and for products with extremely high production volumes and densities. Road transport is the preferred option in the majority of other cases. As a result, a large variety of truck configurations are used to increase truck payloads and decrease marginal equipment and labour costs.

In recent years, more stringent road transport regulation, *Chain of Responsibility*, was introduced that assigned liability and compliance requirements to supply chain parties rather than the transport operator or driver. The implications of *Chain of Responsibility* and *Fatigue Management* regulations on forestry supply chain are significant, as supply chains are fragmented and terminal congestion, for export chains, is an issue with consequences for all members.

2.2.1 Bulk Cargo Export Supply Chains

Raw materials are one of Australia's main physical goods exports. A large proportion of raw materials are exported in bulk - as opposed to containerised transport which is more common for manufactured goods. Close to one billion tonnes were exported in bulk from the continent in 2016/17 financial year (Ports Australia, 2019). Approximately 90% solid bulk exports are made up of iron ore and coal, followed by grain (2.9%), alumina (2.1%) and forest products (1.6%) (see Table 1). Most raw materials undergo limited processing or manufacturing. Given the limited size of the Australian population and demand for large quantities, a vast proportion of raw materials are exported. Therefore, while significant amounts of raw materials are extracted, refined or harvested, the supply chains for many of these commodities, including forest products, consist of relatively few processing stages and typically include a consolidation stage in close proximity to or on a marine terminal wharf.

Table 1 Australian Maritime Exports in Bulk by Commodity Type

Commodity*	Throughput (million tons)		Share of Total Exports	
	2015/2016	2016/2017	2015/2016	2016/2017
Iron Ore	625	657	66.7%	67%
Coal	232	232	24.7%	23.7%
Grain	21	28	2.2%	2.9%
Bauxite, Alumina, Aluminium	20	21	2.2%	2.1%
Forest Products [a]	14	16	1.4%	1.6%
Other Bulk Cargo Exports	26	26	2.8%	2.7%
Bulk Cargo Exports	938	980	100%	100%

[*] figures compiled from Ports Australia (2019), Tasmanian Ports Corporation (2018), Southern Ports (2017)

[a] figure includes author estimates (additional detail in Table 2)

There are a limited number of marine terminals across the Australian territories from which bulk goods are exported. Many terminals are situated in relative proximity to the sites where raw materials are produced. However, approximately 40 bulk cargo ports (Ports Australia, 2017) are spread over the 25,000 kilometres of coastline of the Australian continent. Consequently, raw materials are generally transported large distances to reach the closest export facility. Furthermore, several logistics chains may intersect at a marine terminal.

There are a series of consequences of the focus on raw material exports through a limited number of bulk cargo marine terminals, mainly: (1) Many raw materials can be considered commodity products that are generally difficult to distinguish from other similar products. Commodity products tend to generate relatively low returns for firms per unit sold. Therefore, supply chains for commodity products are typically efficiency-focused; (2) Given the low margins per unit of product sold, the viability of commodity products supply chains relies on high volumes of production and sales. High production volumes entail significant supporting infrastructure requirements. As a result, organisations are incentivised to ensure high levels of infrastructure utilisation to cover the fixed costs. Infrastructure may therefore be shared amongst multiple organisations and supply chains to cover fixed costs; (3) Multiple, uncoordinated supply chains intersecting at bulk cargo ports are prone to generate congestion, both on the landside, on road and rail, as well as on the maritime side.

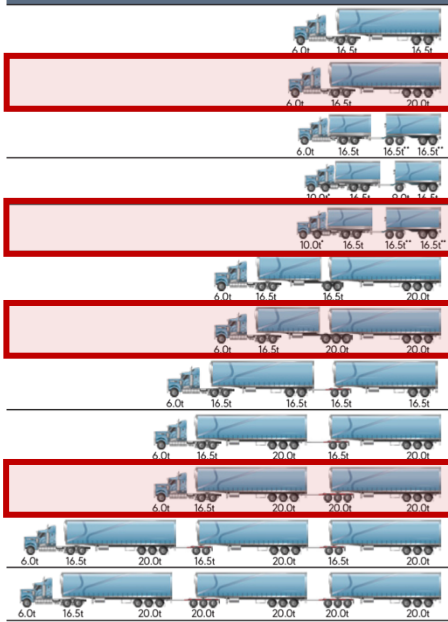
2.2.2 Common Transport Modes

The most common transport modes utilised in Australia are discussed, first for general freight transport and next for forest products transport.

2.2.2.1 General Transport

All three transport modalities are utilised for bulk cargo in Australia, road, rail and barge (Commonwealth of Australia, 2018). Road transport is used for many bulk commodities, primarily when raw materials dispersed over relatively large distances, such as forests or plantations, and where production is insufficiently large to justify the use of other transport modalities, such as smaller mines. Barge transport is sometimes used in coastal areas. Rail transport infrastructure is available between and within major populous area and where extremely high volumes of cargo require transport over relatively large distances - e.g. iron or coal mines to coastal export facilities (BITRE, 2018a).

The vast distances of Australian territories combined with the concentration of industries and populous areas also led to the development and use of larger truck configurations compared to Europe and North America (PwC, 2017). Larger truck configurations significantly increasing the transport capacity of individual trucks. Typical configurations include rigid trucks, with 1 trailer or semi-trailer up to 42.5 tons gross weight that can access the majority of Australian roads, 2 semi-trailer configurations called B-doubles, up to 62.5 tons, 2-3 trailer configurations weighing up to 102 tons, and 3-4 trailer combinations weighing up to 122 tons (NHVR, 2018). The most common truck configurations over 42.5 tons gross mass are illustrated in Figure 1. Common truck configurations used in forestry supply chains and the case studies in this research are highlighted in the red boxes. Additional accreditations, technology and equipment improvements can increase the gross mass permitted by regulators. Truck configurations over 42.5 tons can access a more limited road network but have the ability to carry significantly higher payloads than smaller configurations.



Description	Maximum Length (metres)	Maximum Regulatory Mass under GML (tonnes)
5 Axle Semitrailer	≤ 19.0	39.0
6 Axle Semitrailer	≤ 19.0	42.5
3 Axle Truck and 4 Axle Dog Trailer	≤ 19.0	42.5
4 Axle Truck and 3 Axle Dog Trailer	≤ 19.0	42.5
4 Axle Truck and 4 Axle Dog Trailer	≤ 19.0	42.5
8 Axle B-double	≤ 26.0	59.0
9 Axle B-double	≤ 26.0	62.5
9 Axle A-double	≤ 36.5	72.0
11 Axle A-double	≤ 36.5	79.0
12 Axle A-double	≤ 36.5	82.5
16 Axle A-triple	≤ 53.5	115.5
18 Axle A-triple	≤ 53.5	122.5

Figure 1 Common Regulated Truck Combinations in Australia

Source: National Heavy Vehicle Regulator (2018)

The focus on road transport and the absence of railway infrastructure in many areas of Australia have a series of implications for bulk cargo supply chains: (1) Higher gross mass allowances for trucks imply that higher payloads can be carried per truck tractor head and per driver; (2) Marginal costs for fuel and labour are typically reduced when using higher capacity trucks; (3) The comparative cost advantage of road versus rail transport can be maintained for a longer range of distances therefore making road transport an attractive alternative in a large proportion of cases.

2.2.2.2 Forest Products Transport

In forest products supply chains, road transport is used due to the dynamic nature of resource harvesting and for the relative proximity of the harvesting sites to the processing or storage facilities. Even in cases where rail infrastructure is in close proximity to inland processing and storage facilities and provides a direct connection to coastal export hubs, rail is typically not considered a viable alternative. For example, in Tasmania, the Surrey Hills wood chip mill and in Victoria, the Myamyn wood chip mill are both situated adjacent to rail tracks leading to the respective coastal export facilities. In both cases, road transport is preferred to rail. Initial discussion with the representatives of the organisations involved in forest products supply chains highlighted that rail was considered an expensive option, primarily due to the high infrastructure and rolling stock costs (locomotives and wagons). The was aware of one example where logs were transported by rail from Southern Tasmania to Bell Bay (north-eastern Tasmania, and one of the island's coastal export facilities) using log-tainers, wagons with adaptable supports which can be lowered to allow containers to be stacked on top to improve rolling stock utilisation[1].

2.2.3 Road Transport Regulation

In recent years, more stringent road transport regulations, *Chain of Responsibility*, was introduced. These regulations assign liability and compliance requirements to all supply chain parties rather than the transport operator or driver (NHVR, 2019). Liability for such practices falls both on the organisations as well as people in organisations. While a relatively recent development, the regulation impacted significantly supply chains, as parties along the chain were made liable for contractual terms and practices that could be conducive to unsafe driving practices or accidents.

Fatigue Management, a part of *Chain of Responsibility*, aims to reduce the occurrence and risk of accidents due to operator fatigue. At an individual level, fatigue management includes, strict monitoring of operator hours, mandated rest brakes during driving hours, and attention to rest and fatigue outside working hours.. At an organisational level, along the supply chain, companies should demonstrate having taken precautions and installed safeguards to reduce their potential impact on employees' or contractors' fatigue. Consequently, participants in the supply chains became started investigating and implementing approaches to ensure compliance with *Chain of Responsibility* and *Fatigue Management* regulations.

The next section discusses plantation forestry exports, a subset of bulk cargo export supply chains.

2.3 Plantation Forestry Export Supply Chains

This section briefly presents a discussion on plantation forestry and bulk exports of forest products from plantations.

2.3.1 Plantation Forestry

Australian commercial forestry plantations covered an area of 1.94 million hectares in 2017-18, comprising of approximately 1 million hectares of softwood and 0.9 million hectares of hardwood plantations, with a large majority of these plantations centred around one of the 15 national processing hubs (Downham and Gavran, 2019). Hardwood (primarily *E. nitens* and *E. globulus*) and softwood (primarily *Pinus radiata*) are planted. Softwood is primarily used for sawn-boards and composite materials production. More than 97% of softwood plantations are managed for the production of timber. Approximately 82% of hardwood plantations were managed for the production of woodchips and paper (Downham and Gavran, 2019). The resulting forest products from hardwood plantations are typically exported in log or wood chip form for overseas processing into paper pulp.

Plantation forestry in Australia increased considerably with the implementation of Managed Investment Schemes (MIS) particularly focusing on plantations aimed for wood chip production (Mackarness, 2006). In the 1990s, MIS schemes were introduced as an investment

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[1] Tasmanian Railway Corporation Pty Ltd – personal communication 02.10.2017

option to reduce tax exposure. Close to 8 billion Australian Dollars and more than 75,000 investors contributed to investment schemes from their inception (ASIC, 2009). MIS facilitated the increase of Australian plantation footprint to a peak of approximately 1 million hectares in 2008. However, many MIS became unprofitable because of their cost structure and de advent of the global financial crisis. A number of MIS operators including Great Southern and Timbercorp in Western Australia and Gunns Limited in Tasmania faced financial difficulties and eventually declared bankruptcy (Brown, Trusler and Davis, 2010). Consequently, while many plantations established using MIS funding, a large proportion were not harvested at the expected rotation-age. As the forestry sector recovered, the production and export of wood chips and logs also increased.

2.3.2 Forest Products Exports

In this research, the main forest products considered are logs and wood chips as they represent the majority of forest products exports in bulk and also share similarities with other bulk cargo supply chains. Approximately 6% of forest products exports are represented by timber products – such as veneers, plywood boards, medium- and high-density fibre boards or laminated panels. Timber products supply chains are considerably more complex and consist of additional manufacturing stages. However, these are generally exported in containers or break-bulk form rather than in bulk and will not therefore be considered in this discussion and the remainder of this research.

Forest products export supply chains contain relatively few processing stages, particularly for logs and wood chips. Log export supply chains contain a harvesting stage, where trees are felled, processed into logs and stored roadside. Logs are loaded onto trucks and delivered to a port facility where they are stored in expectation of arriving vessels. This transport stage may include transfer between different transport modalities such as rail. Once vessels arrive on berth, they are loaded and sail to their destinations where products are unloaded. Some final customers operate manufacturing plants on the docks, therefore avoiding destination transportation, whereas in other cases, additional transportation is required. Logs can be processed into veneers, sawn-boards, wood chips for paper production, manufactured wood products or fuel.

Wood chip export supply chains share numerous similarities with logs, however given the additional product processing, are typically more complex. As before, trees are harvested. The trees may be directly processed on site into wood chips using in-field chipping equipment or cut into logs and stored roadside. In wood chips are produced in-field, containers for storing the product or available transportation are required. Logs are transported, primarily by truck, to seaside or offshore processing facilities where they are transformed into wood chips. Additional transportation is required when wood chips are produced offshore to bring the products to port facilities. In-field wood chip production is typically delivered directly to seaside wood chip export terminals. Wood chip vessels are loaded at port facilities and sail to their destinations for unloading. Wood chips can be processed into pulp for paper production, manufactured wood products or used as fuel for energy production. A representation of a typical forest products export supply chain, particularly focused on wood chips is shown in Figure 2.

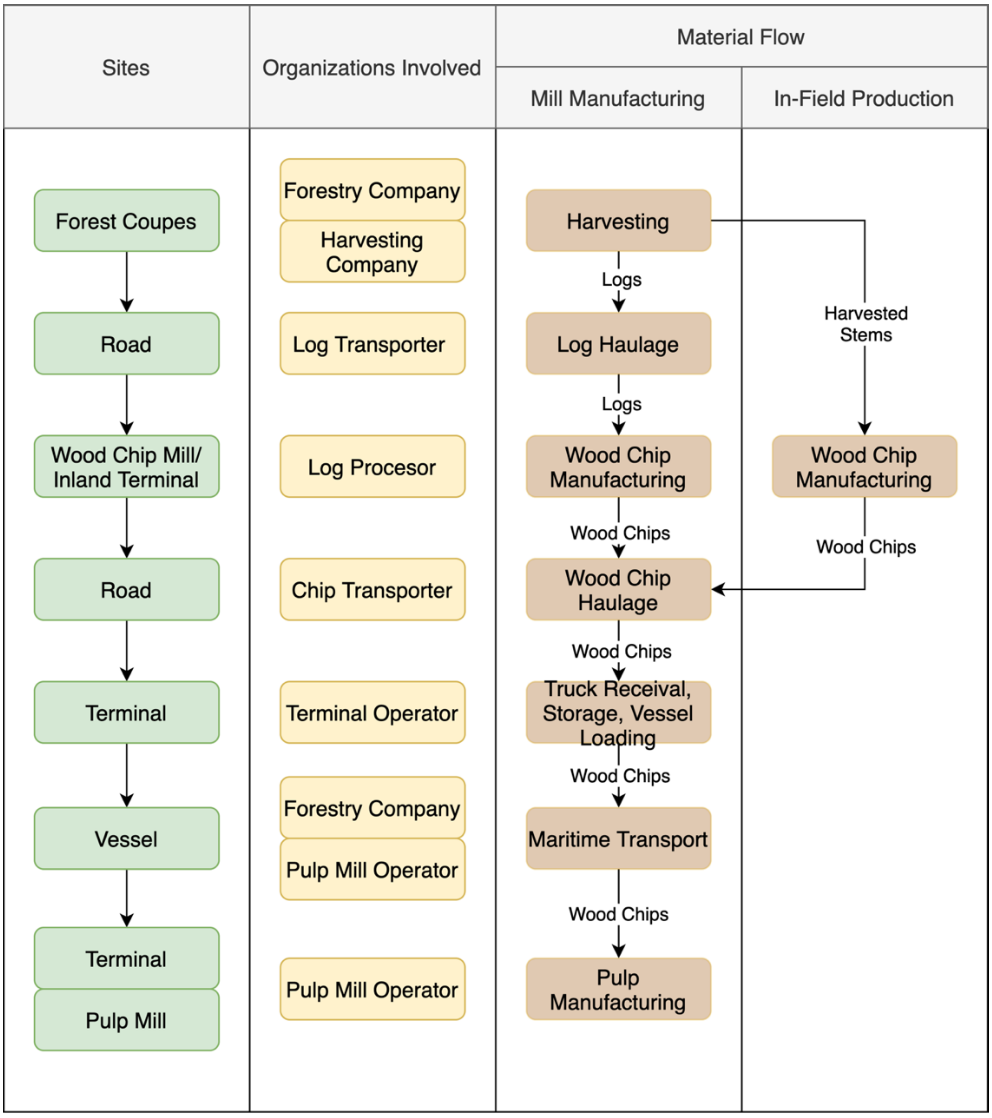

Figure 2 Wood Chip Export Supply Chain - Sites, Organisations and Processes (Researcher's elaboration)

While forest products export supply chains have relatively few processing stages, they derive significant complexity from their organisational setup and fragmentation. Nearly every stage of the supply chain is performed by contractors, and in some cases, by multiple layers of sub-contractors. Plantation owners usually contract forest managers to oversee the plantations during growth and the harvesting. Forest managers typically outsource the harvesting and in-field chipping to specialised contractors. Product transportation may be performed by the harvesting contractors or outsourced to external companies by the harvesting contractors or forest managers. On- or off-shore processing and storage facilities may also be performed by third parties. Vessels may be owned and operated by final customers or chartered for a voyage or long-term. Consequently, the large number of individual organisations participating in forest products export supply chains can generate significant operational and communication challenges. These challenges can also be exacerbated by the intersection of multiple supply chains at port facilities.

2.3.2.1 Forest Products Exports

Forest products exports consist primarily of wood chips, logs and timber products. Total wood chip exports in the 2016/17 financial year (FY) totalled approximately 12 million tons (see Table 2) while log exports totalled approximately 3 million tons (see Table 3).

Table 2 Main Wood Chip Export Facilities and Throughput Figures (2011 to 2017)

State	Port*	2016/2017	2015/2016	2014/2015	2013/2014	2012/2013	2011/2012
VIC	**Portland**	3,838,940	3,314,339	3,163,890	2,269,966	1,857,764	2,013,968
	Geelong	1,200,000[a]	1,200,000[a]	1,266,661	931,305	942,172	703,097
TAS	**Bell Bay**	1,508,508	1,519,975	1,454,800	1,457,621	718,324	633,517
	Burnie	1,479,168	1,095,680	690,433	419,635	185,742	129,285
	Hobart	0	0	0	0	0	26,073
WA	**Albany**	1,752,556	1,420,465	1,165,088	1,398,051	1,090,886	1,373,491
	Bunbury	1,543,783	1,602,058	1,606,760	1,506,607	1,370,648	1,389,988
	Esperance	204,576	15,185	n/a	n/a	n/a	n/a
QLD	**Brisbane**	~400,000[b]	~400,000[b]	200,959	100,057	66,107	71,729
	Gladstone	45,968	112,210	n/a	n/a	n/a	n/a
NSW	**Eden**	900,166[d]	389,863[d]	586,567	[c]	740,137	497,118
Wood Chips Exports (t)		**11,973,499**[e]	**10,679,910**[e]	**10,135,158**	**8,083,242**	**6,971,780**	**6,838,266**

* 2011-2015 figures compiled from Ports Australia (2017), 2015-2017 figures compiled from Ports Australia (2019), Tasmanian Ports Corporation (2018), Southern Ports (2017); a Exporting approximately 1.1 to 1.2 million tons per year (Midway Pty Ltd – communication 14.12.2018); b Exporting approximately 400,000 tons of wood chips per year (Midway Pty Ltd – communication 15.03.2018); c Unknown ; d Calculated by author from total bulk exports mentioned in Ports Australia (2019) and (Plantation Export Group / ANWE - communication 13.10.2017); e Estimate

Wood chip and log exports are concentrated in a limited but relatively stable number of facilities, dispersed across the Australian states, which typically experience increasingly high throughputs. Export terminals are relatively stable outlets for wood chips and logs with few new entrants and some departures. Two and maximum three export facilities can be found in each state. These export facilities are primarily located in high density areas of plantation and native forests. A large proportion of export terminals cater for both wood chips and log exports.

Table 3 Main Log Export Facilities and Throughput Figures Between (2011 to 2017)

State	Port*	2016/2017	2015/2016	2014/2015	2013/2014	2012/2013	2011/2012
VIC	**Portland**	1,771,549	1,474,207	1,267,039	1,292,022	646,551	333,717
	Geelong	[a]	[a]	51,354			
TAS	**Bell Bay**	[b]	[b]	23,765	65,447	58,699	18,917
	Burnie	[b]	[b]	226,989	130,017	102,233	144,079
	Hobart	[b]	[b]		60,944	65,749	113,112
	TasPorts	636,364 [b]	412,629 [b]				
WA	**Albany**	48,777	18,958	n/a	n/a	n/a	n/a
	Bunbury	[a]	67,765	64,558	67,154	8,597	42,567
	Fremantle	23,894	25,836	65,006	43,797	48,983	n/a
QLD	**Townsville**	n/a	n/a	n/a	n/a	90,700	318,696
	Brisbane	n/a	n/a	6,557	2,468	4,029	5,363
	Gladstone	505,422	458,664	n/a	n/a	n/a	n/a
NSW	**Eden**	[a]	[a]	144,158	n/a	93,203	93,407
SA	**Adelaide**	40,049	87,627	85,454	78,300	221	n/a
Log Exports (t)		**3,026,055[e]**	**2,526,728[e]**	**1,934,880**	**1,740,149**	**1,119,085**	**1,170,073**

* 2011-2015 figures compiled from Ports Australia (2017), 2015-2017 figures compiled from Ports Australia (2019), Tasmanian Ports Corporation (2018), Southern Ports (2017); [a] Unknown; [b] TasPorts is the entity that operates Bell Bay, Burnie and Hobart ports. The corporation reports aggregated figures for all ports; [e] Estimate. Actual figures are likely higher.

The port of Portland in Victoria (VIC) has consistently been the largest exporter of logs and wood chips in Australia. Anecdotally, the port is the largest exporter of wood chips in the world[2]. Together with the port of Geelong, Victoria is the largest wood chip and log exporter in Australia. Western Australia (WA) and Tasmania (TAS) are the second and third largest exporters of wood chips and logs. Tables 2 and 3 summarise wood chip and log exports from 2011 to 2017 by state and facility. During the 6 years for which data is available, a vast proportion of ports have experienced increasing throughput. In some cases, significant increases can be observed (e.g. Burnie, Bell Bay and Geelong). As a consequence of their scarcity and throughput increase, many export terminals are facing significant truck and berth congestion challenges.

2.3.2.2 Forestry Supply Chains Regulation

The implications of *Chain of Responsibility* and *Fatigue Management* regulations on forestry supply chain are significant, as supply chains are fragmented and terminal congestion, for export chains, is an issue with consequences for all members. The fragmentation of forestry supply chains, with multiple layers of contractors and sub-contractors, means that in order to ensure regulatory compliance, companies and contractors should have a better understanding and improved visibility into one-another’s business. At an industry level, trucking, contractors and industry associations established work groups to develop best practices. Individual

[2] Australian Bluegum Plantations Pty Ltd – personal communication 27.11.2018

transport operators adopted technology tools such as *electronic work diaries* to facilitate accurate data capture from trucks and drivers. However, at a supply chain level, fewer developments appear to have taken place, as relationships tend to be governed by a principal-contractor mentality. In forest products export supply chains, terminal congestion both land- and seaside appears to be a ubiquitous challenge. Some of the consequences of congestion, beyond the increase in costs and decreased operator and truck productivity, relate to the uncertainty generated by truck waiting times. As waiting times uncertainty increases, so does the possibility that operators are unable to continue their shift or return home under their mandated working hours, increasing the risk of regulation compliance breaches. While organisations recognised these risks, terminal congestion management and fatigue management did not appear to be jointly considered.

The next section discusses road and port congestion management approaches utilised by practitioners to tackle either road or port congestion.

2.4 Road and Port Congestion Management

Road and truck congestion are recognised as issues in road areas as well as for major port facilities in Australia. Typical approaches considered to mitigate congestion can be categorised in infrastructure or technology investments, policy changes, and market-based mechanisms to influence capacity availability or use and instantiate behavioural changes. This section discusses congestion management approaches in the Australian road and port environment.

2.4.1 Road Congestion Management

This section draws heavily from the "*Congestion and Reliability Review*" (Austroads, 2016) which discusses the major challenges with respect to road congestion and suggests a series of approaches to address this issue. Austroads is an organisation governed by a board of representatives of Australasian road and transport authorities. While road and port congestion have some differences, it is expected that some measures proposed for roads can be useful in port environments. This report was included due to its depth of analysis and the variety of congestion mitigation methods included.

The congestion management approaches considered in the "*Congestion and Reliability Review*" are presented in Figure 3. Interventions are distinguished in demand and supply for road infrastructure. Subsequently, interventions are categorised in improved planning, modal shift, behavioural change and operational efficiency and optimality. The individual approaches are then presented in a matrix with the indicative cost of the approach on the x-axis and the indicative cost-benefit ration on the y-axis. Six clusters of congestion management interventions emerge from the figure: 1. Strategic interventions; 2. 'No regrets'; 3. Low Budget; 4. Medium Budget, 5. High Budget and 6 Marginal Benefit.

Broadly strategic interventions are perceived as having the highest cost-benefit potential. This is likely due to the fact that strategic interventions can include regulatory instruments that generate revenue – such as permits or taxes. The '*No regrets*' and Low budget clusters appear to focus primarily on technology interventions such as '*smart ramp metering'*, '*traffic signal optimisation*' or '*variable speed controls*'. The Medium and High budget clusters are more focused on infrastructure investment and modal shift towards public transport. Critically, in comparison to the technology intervention, these approaches seem to deliver similar if not lower cost-benefit ratios. The Marginal payoff cluster contains "*projects that are susceptible to execution risk*". The majority of these interventions generally entail a behavioural change in road users such as staggering working hours, e-work or car-pooling.

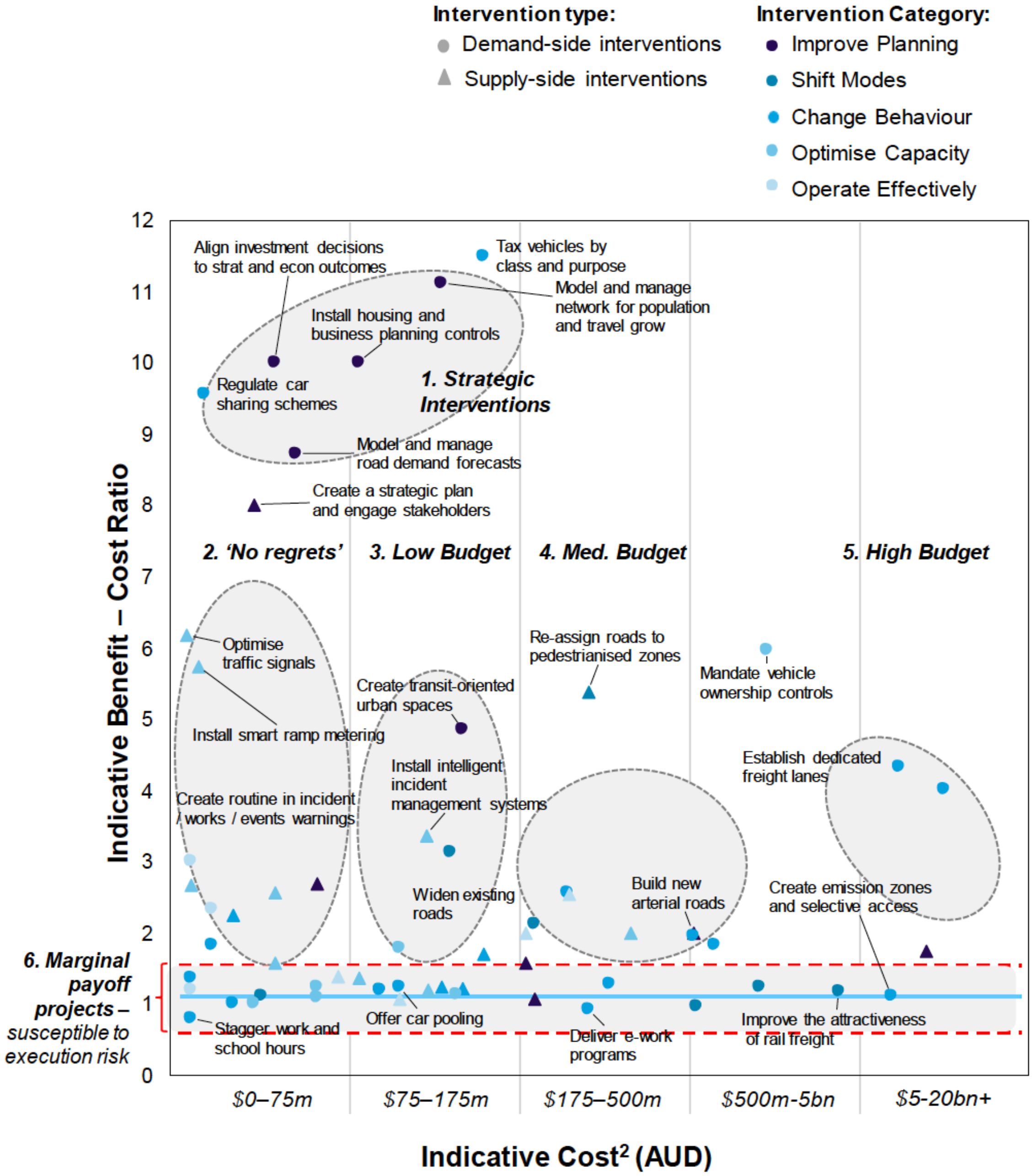

Figure 3 Typical Road Congestion Management Methods Considered in Australia
(Source: Austroads (2016). Reproduced with permission from authors)

Several interesting insights emerge from analysing the congestion management initiatives considered and the way in which these initiatives are evaluated: first, the benefits of congestion management interventions are evaluated from a monetary perspective which can potentially detract from their key aim of reducing congestion. Monetary benefits can be calculated as time not spent in traffic by road users. In this case, an increase in the monetary benefit would entail a reduction congestion. However, monetary benefits can also entail increase in tax revenue. In this case, although the approach is effective in generating money, it may not be as effective in reducing congestion. Second, the road user behavioural component of technology initiatives for congestion management is typically not considered. Road users appear to be considered as compliant to technology-instantiated. Conversely, initiatives specifically reliant on road users' behavioural changes are labelled as having an uncertain outcome and marginal outcome.

2.4.2 Port Congestion Management

Landside congestion and management in Australian ports is primarily monitored and reported on for the country's largest international container ports, Melbourne, Sydney, Brisbane, Adelaide and Freemantle. The Australian Government issues yearly "*Waterline*" report detailing the ports' throughput, productivity and landside performance (BITRE, 2017b, 2017a, 2018b). All terminals on which figures are reported use terminal appointment systems (TAS) also called vehicle booking systems (VBS) to manage the landside interface and congestion. It is unclear what drivers were behind the booking systems' implementations. A large proportion of stevedores (e.g. Hutchison Ports, DP World) have a large international presence and standardised interfaces. It is therefore likely that these operators introduced or facilitated the adoption of appointment systems in Australian international container ports. Similarly, stevedores operating at a national level (e.g. Patrick, Qube and Toll) have also introduced appointment systems in the terminals they operate. Toll also operates a container terminal in Tasmania where it plans to introduce an appointment system[3].

Appointment systems have helped reduce landside congestion in these international container ports and partially shift truck arrivals away from peak times (Davies and Kieran, 2015); however, they have not been without issues. One of these issues is the unavailability of truck arrival slots when and to those transporters that would require them most. To address this issue market-based mechanisms have been proposed to mediate the terminal users' behaviours and improve the allocation of slots to those transporters that value them most (IPART, 2008). As noted in the previous section (3.3.1) the focus on market-based approaches to address landside congestion at terminals is indicative of the type of behavioural moderating approaches considered in the Australian port and maritime logistics space.

The next section provides a summary reflection of this chapter.

2.5 Summary Reflection

This chapter has provided an overview of the context of this research, mainly discussing issues regarding Australian export supply chains, congestion management and plantation forestry.

The contextual factors discussed above can have several implications on this research:

- The limited number of bulk cargo marine terminals appears to lend itself to a case study rather than a quantitative exploration; This chapter provided information that guided the case study selection process (detailed in Section 4.5.1).

[3] Tasmanian Ports Corporation Pty Ltd – personal communication 23.08.2019

- The regulatory and historical factors highlighted in this section sensitised the researcher towards contextual factors that may influence the behaviours of individuals and organisations involved in the research.
- The similarities between forest products and other bulk cargo export supply chains may entail that the approach utilised in this research could be useful in other bulk cargo contexts; similarly, some findings of this research may sensitise researchers working in other types of bulk cargo supply chains.

The next chapter describes the key research literatures pertaining to this research: port-centric supply chains, landside congestion management, information and digital tools in the context of socio-technical systems.

Chapter 3 Literature Review

3.1 Introduction

The previous chapter discussed the context within which the research was conducted. Three aspects are considered relevant from a contextual perspective: the Australian bulk cargo export supply chains, Australian plantation forestry export supply chains and landside congestion management initiatives.

This chapter describes the key research literatures pertaining to this research: port-centric supply chains, landside congestion management, information and digital tools in the context of socio-technical systems.. The structure of this chapter is:

- Section 3.2 presents a discussion on the port-centric supply chains research literature. The analysis of the research literature relating to port-centric supply chains aims to provide an understanding of the rationale for ports and marine terminals to become more involved with aspects of their users' supply chains.[4]
- Section 3.3 discusses the extant research on congestion, its impact and the mitigation strategies adopted by maritime terminals and regulators. This section highlights that currently there is limited understanding of the factors conducive to the appearance of congestion, particularly with regards to factors that may emerge outside the terminals. As a result, the courses of action to mitigate congestion are rarely considered with respect to contributing factors to the appearance of congestion.[5]
- Section 3.4 explores the research literature on information and digital tools in the context socio-technical systems. The lens of '*wicked*' problems is considered as a conceptual tool for a holistic understanding of socio-technical systems. The research literature on participatory design provides the methodological framework for investigating socio-technical systems and is sensitive to the existing and potential role of information and technological artifacts. Finally, the role of information systems in socio-technical systems and their application and impact in supply chains and landside congestion management are explored.
- Section 3.5 aggregates the research problems identified throughout this chapter and formulates the following research questions:

  RQ-1. *What congestion factors, their interrelationships, and implications can be identified and understood?*

  RQ-2. *How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?*

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[4] This section draws from Neagoe, M., Nguyen, H.-O., Taskhiri, M. S., and Turner, P "Port terminal congestion management. An integrated information systems approach for improving supply chain value." In Proceedings from the Australasian Conference on Information Systems, pp. 1-9. 2017

[5] This section draws from Hvolby H-H., Kenn S-J., Neagoe M., Vestergaard S., Turner P. (2019b) "Collaborative Exchange of Cargo Truck Loads: Approaches to Reducing Empty Trucks in Logistics Chains." In: IFIP International Conference on Advances in Production Management Systems, Springer Berlin Heidelberg

RQ-3. *What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?*

3.2 Port-Centric Supply Chains

The analysis of the research literature relating to port-centric supply chains, and particularly supply chain integration aims to provide an understanding of the rationale for ports and marine terminals to become more involved with aspects of their users' supply chains and the ways in which this can be achieved. The role of digital tools and information sharing in supply chains is also an important consideration in this chapter.

3.2.1 Defining Supply Chain Management

The concept of supply chain management (SCM) deals with the management of the flow of materials and the equally important associated flow of information streaming from one end to another (Pagell, 2004; Power, 2005). The ideas underpinning the concept relate to alignment and integration (Storey *et al.*, 2006; Childerhouse and Towill, 2011) between different functions and processes within and between organisations. Adopting the alignment and integration concepts also requires a reorientation of the competition. Traditionally, firms compete against one another, however the supply chain perspective argues that supply chains rather than individual firms compete (Christopher, Peck and Towill, 2006). Rather than looking to optimise internal efficiency or to control scarce resources, in a 'zero-sum' game, companies in a supply chain strive to coordinate and align their goals, avoid opportunistic behaviour and engage in 'win-win' relationships (Storey *et al.*, 2006).

Table 4 Selected Supply Chain Management Definitions

Authors	Supply Chain Management Definitions
(CSCMP, 2018)	"*Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.*"
(Hugos, 2018)	"*Supply chain management is the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served.*"
(Monczka *et al.*, 2009)	"[SCM] *endorses a supply chain orientation and involves proactively managing the two-way movement and coordination of goods, services, information, and funds (i.e., the various flows) from raw material through end user.*"
(Mentzer *et al.*, 2001)	"*The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.*"
(Stevens, 1989)	"*The objective of managing the supply chain is to synchronise the requirements of the customer with the flow of materials from suppliers in order to affect a balance between what are often seen as conflicting goals of high customer service, low inventory management, and low unit cost.*"

Whilst there is some agreement regarding most foundational concepts of supply chain management, there appears to be less agreement amongst researchers in defining the term. Selected definitions of supply chain management are presented in Table 4. These definitions highlight commonalities as well as concepts that are used and developed throughout this research. The integrative philosophy to managing the flows from end-to-end, intra- and inter-organisations is a common element of all definitions. Importantly, a wide range of stakeholders are identified in the supply chain which is suggestive of the fragmentation and core-competency focus trends (Storey *et al.*, 2006). Both Hugos (2018) and Stevens (1989) highlight that multiple, often conflicting objectives should be balanced, not only amongst organisations, but also in the way supply chains function and are organised. The Council of Supply Chain Management Professionals' (2018) definition appears to be more frequently used in the literature and is also more explicit about the planning horizon, functions and partners. This definition was therefore considered most suitable for this research.

Logistics and supply chain are often used interchangeably. However, CSCMP (2018) define the logistics function as a subset of supply chain activities. The definition of logistics adopted in this research is "*that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements.*" (CSCMP, 2018).

3.2.2 Forestry Supply Chains

Forestry supply chains are typically complex with multiple, often small entities, interacting to manage the processes involved in manufacturing wood products. Forestry supply chains have a divergent structure in the sense that the tree is decomposed into several products (Ramage *et al.*, 2017). Forestry supply chain decisions are often analysed in strategic, tactical and operational planning horizon. Strategic decisions can involve forest management and silvicultural regimes, the construction of mills, or road infrastructure or process changes. Tactical decisions can include the allocation of products to individual customers, production and logistics routing planning. Operational decisions include logistics scheduling and process control (D'Amours, Rönnqvist and Weintraub, 2009).

The logistics task for forestry products is often carried out by truck, although multi-modal and intermodal transport options are also used (Kogler and Rauch, 2018). Rail transport of forest products is also used in some instances (Etlinger, Rauch and Gronalt, 2014; Flodén, 2016). Similarly, water-based transport has also been considered for the transport of export logs (Munisamy, 2010) and wood pulp (Karttunen *et al.*, 2012; Nørstebø and Johansen, 2013). Logistics costs can represent more than 40% of the total forestry supply chain costs (D'Amours, Rönnqvist and Weintraub, 2009). Improving the efficiency of logistics planning and scheduling has attracted significant interest from researchers (Audy and Rönnqvist, 2012; Andersson *et al.*, 2016; Malladi and Sowlati, 2017). Although researchers recognise the impact of congestion on operations and costs, there are few examples where congestion is taken into account (Alexandra F. Marques *et al.*, 2014), and no examples of congestion being considered at marine terminals.

3.2.2.1 Modelling Forest Products Logistics

Logistics operations in forestry supply chains are typically modelled using analytic techniques or simulation. Analytic techniques include linear programming and queuing theory approaches. Linear programming is by far the preferred approach to minimise logistics costs or to maximise profits (Ghaffariyan *et al.*, 2011; Sosa *et al.*, 2015b; Andersson *et al.*, 2016; Scholz *et al.*, 2018). Forestry supply chains are however dynamic systems subject to uncertainty. The interactions between the different elements operating in the chain and also random events can lead to delays and queuing (Windisch *et al.*, 2015). Analytic techniques cannot easily account for stochastic events. Researchers have postulated that neglecting interactions between supply chain elements and random events can lead to underestimating costs by approximately 20% (Fernandez-Lacruz, Eriksson and Bergström, 2020). Consequently, some researchers have turned towards simulation modelling.

Discrete-event simulation (DES) is one of the most commonly used simulation methods in forestry logistics modelling (Windisch *et al.*, 2015; Kogler and Rauch, 2018; Fernandez-Lacruz, Eriksson and Bergström, 2020). Opacic and Sowlati (2017) Kogler and Rauch (2018) present comprehensive reviews of discrete event simulation in forestry supply chains. Discrete-event simulation models are typically used to perform sensitivity analyses on systems, assess the performance of various options and assist in bottleneck identification (Marques *et al.*, 2014). Fernandez-Lacruz, Eriksson and Bergström (2020) used DES to evaluate the impact of intermediary storage terminals on forest products logistics costs. Marques *et al* (2014) used DES to explore the impact of the proportion of unannounced and peak period truck arrivals on truck unloading times at a mill. Etlinger, Rauch and Gronalt (2014) used DES to understand the impact of additional infrastructure, volume increases and rail equipment changes in a rail terminal for forest products. This research intends to build on the exiting research on DES and study the impact of additional infrastructure, volume increases, transport equipment and technology on truck unloading times in bulk cargo marine terminals for forest products.

3.2.2.2 Forest Products Logistics Coordination

A significant forestry logistics models tend to be premised on the assumption that transport operations can be centrally controlled (Sosa *et al.*, 2015a; Malladi and Sowlati, 2017). An alternate stream of research has recognised that a range of actors interact in forest products logistics and that the levels of coordination between these actors may vary significantly (Audy *et al.*, 2012; Rönnqvist *et al.*, 2015; Sanei Bajgiran, Kazemi Zanjani and Nourelfath, 2016). Although research has analytically shown that increased coordination of actors in forest products logistics can lead to increased transport efficiency and reduced costs, examples of coordination in practice are rare. Audy and Rönnqvist (2012) highlight that two practical issues remain unsolved in relation to logistics coordination: how would the costs and benefits of collaboration be distributed and; what information are companies willing to share (Audy and Rönnqvist, 2012).

The challenge of fostering collaboration between stakeholders operating in forest products logistics has been recognised in a review of forest operation research open problems (Rönnqvist *et al.*, 2015). More specifically, the authors highlighted the absence of principles for establishing practical collaborations in forest products logistics as well as the lack of a methodology to facilitate coordination of stakeholders with divergent interests and individual agendas. This research intends to contribute to this discussion with an approach that hopes to facilitate the alignment of perspectives amongst stakeholders and potentially foster information sharing and collaboration.

The next section presents the stream of research concerned with the role of maritime terminals in supply chains.

3.2.3 Marine Terminals in Supply Chains

Ports have traditionally been considered as the interface between sea and land transport (Pettit and Beresford, 2009), providing shelter and berthing space for vessels and infrastructure and temporary storage for cargoes. More recently, the role of ports in supply chains has evolved towards functional nodes in logistics networks (Ascencio *et al.*, 2014). Ports are defined as "*a geographical area where ships are brought alongside land to load and discharge cargo – usually a sheltered deep-water area such as a bay of river mouth*" (Stopford, 1997). A port generally consists of one or more terminals, where a terminal is "*a section of the port consisting of one or more berths devoted to a particular type of cargo handling*" (Stopford, 1997). The different types of cargoes handled by terminals have different peculiarities that can influence their setup and operations.

3.2.3.1 Types of Maritime Terminals

The most common types of cargoes handled by marine terminals are dry bulk, dry liquid, break-bulk, general cargo and containerised. Dry bulk cargoes – typically ores, cement, wood chips etc – are generally commodity products with a low value to weight ratio driving a focus for efficiency in such terminals. Terminal equipment is often designed to handle one type of commodity in one direction – import or export (Comtois and Lacoste, 2012). Dry bulk shipping is primarily tramp – unscheduled services – due to the nature of production and demand cycles. Furthermore, dry bulk traffic is generally imbalanced. Consequently, economies of scale and diminishing terminal loading and unloading times can offset some of the empty travel costs (Comtois and Lacoste, 2012). Tramp shipping contracts generally specify lay times – terminal loading and unloading durations (Desrosiers, 2012). The cargo owner and terminal operators are charged demurrage fees for loading and unloading times beyond the specified vessel lay time. Therefore, cargo owners and terminal operators are typically incentivised to ensure the timeliness of vessel operations.

Liquid bulk terminals primarily handle crude oil and petroleum products and have purpose-built infrastructure to ensure the safe handling of the product. Break-bulk and general cargoes are delivered, handled and loaded on board vessels individually or in packages. Examples of break-bulk cargoes can include wind turbine blades or industrial equipment. Containerisation has gained increased popularity and has become one of the main ways of transporting a wide range of products and goods. Container shipping services are more regular, typically scheduled by international shipping lines. The appeal of containerised goods stems from the standardised loading units which increases handling speed dramatically and limits the risks of damaging the products inside. Interestingly, containerisation appears to have stemmed interest for practitioners and researchers alike in understanding the role of ports and marine terminals in supply chains.

3.2.3.2 The Role of Ports and Marine Terminals in Supply Chains

Ports currently play an important role in supply chains, beyond their traditional function of vessel and cargo service provider. Ports serve as node and interaction point between members of different logistics chains (Bichou and Gray, 2004). The pivotal position ports have in supply chains can allow ports and terminals to integrate with maritime and hinterland chains to strengthen their service competitiveness (Tseng and Liao, 2015) and ultimately that of its users' supply chains (Robinson, 2002).

Port supply chain integration includes dimensions such as: information and communication technology, value added services, integrative practices and relationship integration (Song and Panayides, 2008; Tongzon, 2009; Panayides and Song, 2013). Information and communication technology can be used to support information sharing amongst companies. Examples include e-commerce applications (Tseng and Liao, 2015), radio-frequency identification systems (Rizzo *et al.*, 2011) and electronic data interchange (Song and Panayides, 2008) Value added services are those that satisfy a customer requirement which can be monetised and have been found to support customer retention and an improved competitive position of ports (Okorie, Tipi and Hubbard, 2016). Integrative practices include port activities undertaken beyond organisational boundaries (Bichou and Gray, 2004; Panayides and Song, 2008). Relational integration includes forming long-term relationships amongst parties, supported by trust and enhanced communication (Gligor and Holcomb, 2013). These integration dimensions are primarily used for the development of theoretical frameworks.

Researchers have yet to conclusively establish the type of relationship between port supply chain integration using theoretical frameworks and improved port or supply chain performance (Tongzon, 2009; Seo, Dinwoodie and Roe, 2015, 2016; Tseng and Liao, 2015). The development of theoretical frameworks is most often supported by previous research rather than developments in practice. This self-referencing approach of the literature may have been partially responsible for widening the disconnect between theory and practice and potentially for the inconclusive results regarding the type of relationship between integration and performance. From a practical perspective, institutional fragmentation and the conflicting objectives and interests with other stakeholders have often prevented holistic approaches (Bichou and Gray, 2004). Therefore, port, hinterland and maritime operations have been conventionally been considered both in theory and practice in isolation from one another.

3.2.3.3 Port Performance Measurement

Port and terminal performance measurement is an important component to understanding the efficiency and effectiveness of port and terminal operations and to compare current and past performance (Tsamboulas, Moraiti and Lekka, 2012). Traditionally, port performance was measured against optimum values from an operational perspective. In more recent times, financial and economic indicators have been increasingly considered (Talley, 2006).

Operational performance indicators primarily relate to berth and vessel performance and include vessel turnaround and wait time, on-time reliability, berth occupancy and other indicators (Tsamboulas, Moraiti and Lekka, 2012; Brooks and Schellinck, 2013; Cimpeanu, Devine and O'Brien, 2017). On the landside, few performance indicators are considered by ports and terminals. The most common landside performance indicator is the average truck turnaround time (Ramírez-Nafarrate *et al.*, 2017; Torkjazi, Huynh and Shiri, 2018; Yi *et al.*, 2019). Interestingly, (Brooks and Schellinck, 2013, 2015) highlight that port and terminal users – both on the marine and landside - are often more interested in the reliability of port services rather than their speed. Furthermore, they highlight that supply chain users are interested in understanding the landside accessibility of ports and terminals and consequently the levels of truck congestion (Brooks and Schellinck, 2015).

Consequently, measuring performance and congestion in terms of average service times may be insufficient for port and terminal users. Measures of service time reliability may also prove useful in better understanding performance and congestion. Currently, there are no examples of reliability measures of truck turnaround times. However, there are examples of on-time reliability on the maritime side in relation to vessel service times. In this work, maritime indicators will be adapted for the landside logistics.

The next section provides an overview of the research literature on port operations, hinterland and maritime logistics.

3.3 Landside Logistics, Congestion and its Management at Marine Terminals

This section explores the extant research on congestion, its impact on marine terminals and port users as well as congestion mitigation strategies adopted by maritime terminals and regulators. This section highlights that currently there is limited understanding of the factors conducive to the appearance of congestion, particularly with regards to factors that may emerge outside the terminals. As a result, the courses of action to mitigate congestion are rarely considered with respect to contributing factors to the appearance of congestion.

3.3.1 Integrating Hinterland, Maritime and Terminal Logistics

Maritime terminals provide the interface between hinterland and maritime logistics. Although these three logistics stages are intricately interconnected, the research literatures in this area are largely disconnected. The 3 research literatures will be briefly reviewed primarily highlighting the limited efforts in approaching logistics challenges from a more holistic perspective.

3.3.1.1 Maritime Logistics

Maritime logistics is primarily concerned with the movements of goods between different ports. Shipping services can be differentiated into liner, tramp and industrial services. In liner service, ships operate according to a schedule determined in advance. This is similar to a bus service. In tramp and industrial services vessels are hired for individual transports, similarly to a taxi service (Christiansen *et al.*, 2013). The three types of operations influence the types of problems the research literature addresses. Liner shipping problems are primarily concerned with determining the fleet size and mix, service network design and scheduling, fleet deployment, rotation scheduling and sailing speeds (Meng *et al.*, 2013). A large proportion of studies aim to minimise costs for the fleet operator through analytical techniques, mainly consisting of optimisation models (Christiansen *et al.*, 2013; Halvorsen-Weare, Fagerholt and Rönnqvist, 2013). The focus on internal operations and costs is to some extent mirrored in industrial and tramp shipping.

An important difference between industrial and tramp shipping is the focus on cost minimisation of the former and profit maximisation objective of the latter. (Christiansen *et al.*, 2007; Andersson *et al.*, 2010). In industrial shipping, the cargo owner operates or contracts the sea transportation stage which then becomes a cost for the company. In tramp shipping, the transport operator's aim is to maximise the profitability of its transportation assets. This relatively small shift in focus has considerable implications in raising issues within supply chains that can otherwise be overlooked when focusing on internal operations and cost minimisation.

Internal cost optimal solutions can have detrimental consequences for other parties in the supply chain. The optimal transportation pattern from a cost perspective can generate inconveniences to suppliers and customers through inconsistent delivery patterns (Coelho, Cordeau and Laporte, 2013). Furthermore, the recent trend of slow steaming – vessels sailing slower than design speed to reduce fuel consumption - mainly observed in liner shipping, has increased transport times and has been correlated with increased schedule unreliability which in turn increases supply chain uncertainty and inventory costs for customers and suppliers (Meng *et al.*, 2013). Similarly, port operations are affected by unreliable sailing schedules as vessel unloading sequences require frequent adjustments. Slow steaming and increased vessel sizes also narrow the range and number of ports which can be served by a vessel, consequently restricting the available services for customers and increasing travel times by requiring transhipments between main ports of call and secondary destinations (Ferrari, Parola and Tei, 2015). One cause of these detrimental consequences at a supply chain level can be the decision misalignment between different parties.

Integration between elements in the supply chain can generate improved performance beyond that generated through cost optimisation of parts (Andersson *et al.*, 2010; Coelho, Cordeau and Laporte, 2013). Improved performance can be either financial, robustness or flexibility related (Christiansen *et al.*, 2013). The literature on combined problems is relatively scarce. Gunnarsson *et al.* (2006) and Andresson (2011) are amongst the few exceptions that combine facility location and vessel routing problems. As opposed to hinterland logistics where transport units are relatively small, in maritime logistics, transport units are large, sometimes containing days or weeks' worth of production inputs. This can increase the magnitude and impact of supply chain consequences in the case of maritime logistics, therefore increasing their visibility. Whilst the consequences of misaligned decision-making in supply chains have received more attention, the research literature continues to maintain a domain separation, generally treating maritime logistics issues in isolation from the supply chain.

The next section discusses the research literature on coordination and integration in hinterland logistics.

3.3.1.2 Hinterland Logistics

Hinterland logistics are primarily concerned with landside transportation of goods by truck or rail, or barge via inland waterways. Hinterland logistics play an important role in determining supply chains' transportation costs. The costs for inland transportation are generally higher than those for maritime transportation. Moreover, many logistics bottlenecks – such as congestion or insufficient infrastructure – primarily occur in the land transportation stage (Van der Horst and De Langen, 2018). Improvements in logistics coordination amongst actors can increase efficiency and productivity gains (Gansterer and Hartl, 2018), decrease environmental impact, and improve market presence or access (Cruijssen, 2006; Cruijssen, Cools and Dullaert, 2007). A range of actors interact in logistics chains, from competing companies offering similar services (e.g. transport operators) to companies offering complementary services along the chain. Due to their position and heterogeneous nature, stakeholders have different perspectives on logistics and transportation and an often divergent set of performance indicators (Crainic and Hewitt, 2017). Enhanced coordination and integration amongst stakeholders in hinterland transport chains therefore does not happen spontaneously but requires a series of mechanisms (Van Der Horst and De Langen, 2008).

The coordination mechanisms often discussed in the research literature include: incentive alignment, horizontal collaboration or integration, changing firms' scope and collective action. Incentive alignment may include financial penalties, bonuses, or differentiated pricing mechanisms, or non-financial approaches such as dedicated access to facilities and reduced waiting times (Van der Horst and De Langen, 2018). Horizontal collaboration can vary in scope from joint operations management, joint planning to strategic alliances (Cruijssen, Cools and Dullaert, 2007). Changing firms' scope includes vertical integration as well as assigning a third party as an intermediary for coordinating activities (Van Der Horst and De Langen, 2008). Finally, collective action consists of joint working groups including multiple stakeholders to agree on common approaches to address issues (Van der Horst and De Langen, 2018). The research focus on approaches to better integrate and better coordinate the hinterland logistics chain appears to be more developed than that concerning maritime logistics (see Section 3.3.1.1). The developments in hinterland logistics towards exploring horizontal and vertical coordination mechanisms are a first step in acknowledging the inter-relationships between terminal and landside operations. The academic interest in the interplay between terminal and hinterland operations creates a space to further explore and better understand these inter-relationships.

Coordination mechanisms have generally been studied at a relatively high, strategic, abstraction level with few guidelines of how coordination can be implemented. The research of Gumuskaya *et al.*(2020) is one of the few examples of a framework for implementing coordination. The framework is structured in four steps: model operations and relationships, identify conflicting goals, assessing causality and finally assessing information flows. In applying the framework, the researchers found that coordination challenges have several commonalities: goals were often conflicting or competing across organisations, closely interlinked processes and missing or delayed information contributed to the appearance of coordination challenges. The framework developed by Gumuskaya *et al.* (2020) can be used to sensitize the researcher in the investigation of congestion.

The next section discusses the research literatures on port and terminal logistics and links to maritime and hinterland logistics integration and coordination.

3.3.1.3 Terminal Logistics

Container terminal operations are typically divided into five areas: berth, quay, transport, yard and gate operations. Berth and quay operations are referred to as the 'seaside' while yard and gate operations are the 'landside', while transport operations connect the two sides of terminal logistics. Bulk cargo terminal operations can be divided into berth, internal terminals and landside (van Vianen, Ottjes and Lodewijks, 2011).

Seaside operations interface with sea-going vessels by loading and unloading them with cargo. Berthing times are generally seen as non-value adding activities that should be minimised (Vis, Roodbergen and Jan, 2018). Given the imperative for berthing time minimisation, much of the research literature on seaside operations has focused on optimising berth allocation, quay cranes assignment and scheduling (Bugaric *et al.*, 2012; Wang *et al.*, 2018; Correcher, Alvarez-Valdes and Tamarit, 2019; Jos *et al.*, 2019).

Terminal transport operations ensure the connection between the landside and seaside and between different terminals within a port. The types of problems generally addressed in this area relate to vehicle selection (e.g. Duinkerken *et al.*, 2006), quantification of vehicle requirements (e.g. Murty *et al.*, 2005) and the routing and dispatching of vehicles (Carlo, Vis and Roodbergen, 2014). In most cases, the objective of the research papers is to identify the financially or time optimal configuration or schedule of terminal transport operations (Murty *et al.*, 2005; Duinkerken *et al.*, 2006).

Landside operations are the interface with the hinterland transportation. In container terminals, landside operations are often managed to improve the efficiency of terminal equipment (Zhao and Goodchild, 2010, 2013) and, in some cases, also aim to reduce truck turnaround times at the terminal (Huynh, 2009; Chen, Govindan and Yang, 2013; Ambrosino and Caballini, 2015). There has been limited interest in landside operations in bulk cargo terminals primarily because many bulk cargo terminals are fed by trains, barges or conveyors (van Vianen, Ottjes and Lodewijks, 2011) while others consider that landside operations are a less complex logistical and cost-wise challenge when compared to main performance indicator, vessel waiting time (Bassan, 2007).

Whilst individual terminal operations are often treated independently, some researchers have also recognised the potential value of a more integrated approach. Sea- and landside operations have been studied jointly, primarily in order to minimise the vessel turnaround time (Chen *et al.*, 2007; Lee *et al.*, 2010; Wang *et al.*, 2018). However, most researchers use analytic approaches to identify optimal solutions for integrated problems which require the assumption of deterministic settings to solve large instances of a given problem (Carlo, Vis and Roodbergen, 2014). Therefore, the influence of external factors variations such as vessel delays or irregular truck arrival patterns is often overlooked.

Logistics movements outside the terminals' boundaries are often interconnected with terminal operations. On the seaside, vessel delays can trigger multiple adjustments to the terminal's berth plans and yard operations. Vessels can slow down to avoid waiting times and port congestion (Meng *et al.*, 2013). On the landside, different truck arrival sequences can influence the utilisation of quay and yard cranes (Van Asperen, Borgman and Dekker, 2013; Zhao and Goodchild, 2013) and reduce yard re-handling requirements (Zhao and Goodchild, 2010). The interdependency between terminal operations, hinterland and maritime logistics movements suggests that a joint approach in dealing with these issues may generate superior results to individual approaches. Conversely, disjoint approaches focused on improving operational efficiency within organisational boundaries, or within sectors of organisations, can have a detrimental impact on the system. Importantly, the consequences of these approaches can be often obscured beyond the boundaries of the organisation or the sector in which the problem is addressed. One issue that has frequently been addressed in isolation from the logistics chain, as a stand-alone problem generally under the responsibility of marine terminals is landside congestion at terminal gates.

In summary, maritime, hinterland and terminal logistics are intricately interconnected. Nonetheless, research in these areas has been largely undertaken with a limited consideration of these interdependencies. Consequently, while there has been significant progress in understanding the potential avenues or outcomes of tackling challenges arising in hinterland, maritime or terminal logistics, there is still limited understanding as to how these avenues and outcomes can be implemented in practice and therefore achieved. The next section discusses the extant evidence in the research literature on landside congestion factors and consequences.

3.3.2 Congestion Factors, Impacts and Consequences

This section discusses congestion factors, impacts and consequences. Congestion impacts and consequences affect multiple participants in modern supply chains, irrespective of where congestion emerges. Nonetheless, the research literature provides limited insights regarding the factors that contribute to the appearance of congestion. As a result, landside congestion management, particularly in maritime terminals, appears to be largely disconnected from the potential factors which lead to the appearance of congestion. Furthermore, analytical landside congestion management solutions suggest that significant benefits can be achieved. However, there is still limited understanding as to how these outcomes can be implemented in practice and therefore achieved. Empirical investigations of landside congestion management are rare and are mostly concerned with implementation impact rather than providing implementation guidelines.

Congestion is a common issue in transportation, logistics and supply chains whether for freight or passengers. The growth in international trade increases the risk of congestion formation in ports, particularly on the landside due to additional challenges regarding taking initiative, coordination and funding (Meersman, Voorde and Vanelslander, 2012). Congestion can be defined as, *"the presence of delays along a physical pathway caused by the presence of other users"*, where delays are the difference between the recorded and expected travel or service time under uncongested conditions (Kockelman, 2004). Congestion generally implies that transport users impede one-another from accessing transport infrastructure, therefore generating costs for third parties (Meersman, Voorde and Vanelslander, 2012). The two main types of congestion are recurring and non-recurring. Recurring congestion tends to occur regularly in certain locations and times, resulting from an imbalance between supply and demand for transport infrastructure and equipment. Non-recurring congestion is generally caused by unpredictable events such as weather or accidents (Kockelman, 2004). The most common visual indicator for the formation of congestion is the build-up of queues (Meersman, Voorde and Vanelslander, 2012). However, the consequences of congestion are further reaching and more complex than simply time delays.

Congestion can impact the logistics operations of the entire supply chain. Transport operators are most visibly affected by congestion due to time losses in queuing which increase costs, fuel consumption and decrease the productivity of their assets. These impacts ultimately reduce the transport operators' earnings (Huynh, Smith and Harder, 2016). Congestion can be perceived an inconvenience and source of frustration for truck drivers and can also increase the risk of accidents (Meersman, Voorde and Vanelslander, 2012). In ports, the most visible consequences of congestion are the increase in truck turnaround or service times (Davies and Kieran, 2015). Port congestion can cause knock-on consequences in logistics chains. Vessel delays in one port can influence operations in the next port of call as vessels arriving late require schedule adjustments to be serviced. The uncertainty generated by congestion also impacts the port users' supply chains and contributes to an increase in inventory, warehousing, transportation costs (Loh and Thai, 2015) and a decrease in overall transport performance (Meersman, Voorde and Vanelslander, 2012). However, before attempting to mitigate the effects of congestion, it is important to understand the factors leading to its appearance.

Table 5 Marine Terminal Landside Congestion Factors

Factor Type	**Congestion Factors**	**References**
Technical	Infrastructure limitations	(Kockelman, 2004; Meersman, Voorde and Vanelslander, 2012)
Behavioural	Operational disruptions (weather, accidents)	(Meersman, Voorde and Vanelslander, 2012)
	Flawed policy and regulations	(Kockelman, 2004)
Social	Imperfect information flows	(Kockelman, 2004; Motono *et al.*, 2016)

Several congestion factors are considered in the research literature. Kockelman (2004) discusses three main factors for the appearance of traffic congestion inadequate supply of infrastructure, imperfect information flows or flawed policies and regulation. Meersman *et al.* (2012) highlight that port congestion emerges due to the mismatch between the port and logistics capacity, labour and equipment shortages. Weather events are also considered a reason for the appearance of congestion. Motono et al. (2016) are one of the few research papers that discuss factors causing congestion. In their case, one of the main factors identified was 'improper documentation' which was addressed by the terminal operator using a technology platform. The researchers highlighted that previous congestion mitigation methods had ended in failure, likely due to the fact that they were misaligned with the factors causing congestion.

Table 5 summarises the marine terminals landisde congestion factors discussed in the extant literature.

Interestingly, Meersman *et al.* (2012), the researchers posit that the existence of congestion is partially related to the value of ports as scarce goods. It would therefore appear that congestion and ports are inextricably linked with one another. The research literature exploring the factors leading to the appearance of congestion is however extremely limited and presents a relatively restricted view of congestion.

Congestion is often perceived as an issue where its symptoms, primarily queuing, emerge. The most obvious cause for the appearance of congestion is inadequate infrastructure. This may often be the case for recurrent congestion (Kockelman, 2004). Nevertheless, attributing congestion to inadequate infrastructure is a gross simplification of the problem which overlooks a series of important questions: Is the infrastructure inadequate to handle daily, monthly or yearly demand or just temporary peaks? If temporary peaks occur, what are the reasons behind their appearance – regulatory requirements or incentives, upstream or downstream operational uncertainty, pick-up or delivery constraints, equipment unavailability, staff working hours, rostering preferences or preferences? Often, attributing congestion to inadequate infrastructure is a simplification of the problem. This is an issue because, *"problems can be made more difficult by simplifying them [...] The solution may consist in enlarging the system under study to include more of a larger system that contained it in reality"* (Ackoff, 1978). In order to cover this research gap, it is therefore critical to expand the perspective on congestion and take a more holistic view of the logistics chains interacting at marine terminals.

The next section discusses the extant research surrounding landside congestion management approaches in port terminals.

3.3.3 Landside Congestion Management in Marine Terminals

Landside congestion management in marine terminals is not well defined despite the extensive literature on the topic. Most academic research on landside congestion management present various approaches to mitigate congestion. Landside congestion management approaches include technology tools, terminal infrastructure capacity or access expansion and regulatory policies. Technology tools have been used for process automation (Koliousis, 2020) and for managing truck arrivals (Huynh, Smith and Harder, 2016; Ramírez-Nafarrate *et al.*, 2017).Terminal infrastructure capacity or access expansion consist of either the addition of infrastructure or extensions of opening times for deliveries (Maguire *et al.*, 2010). Regulatory policies can include incentives or disincentives for truck operators to disperse arrivals at marine terminals throughout the day (Holguín-Veras *et al.*, 2011; Bentolila *et al.*, 2016).

Landside congestion management approaches generally aim to reduce a performance measure for congestion. Congestion is also not well defined in the extant literature (see Section 3.3.2). Consequently, no unified measure of congestion exists. The average truck turnaround time and average truck waiting time -either expressed in minutes or in monetary equivalents - are the most common measures of congestion (Guan and Liu, 2009; Schulte *et al.*, 2017; Torkjazi, Huynh and Shiri, 2018). However, in some cases truck waiting times include waiting times outside the terminal premise while in other cases they do not. Thus, landside congestion management approaches typically aim to address congestion performance metrics, often truck turnaround and waiting times. In this research, landside congestion management is therefore understood to encompass mechanisms aimed at reducing congestion, measured by predefined performance measurements, instantiated by organisations involved in maritime supply chains and regulatory bodies.

It is important to note that congestion has often generally treated as a "*build our way out*" type of problem (Arnott and Small, 1994 in Cheng, Pang and Pavlou, 2020). In maritime terminals, capacity can be increased through infrastructure expansions to remove a bottleneck. Furthermore, the access to terminal infrastructure can be extended to allow external deliveries to take place at various times during the day (Giuliano and O'Brien, 2007). The adoption of technology tools to addressing congestion has only increased in the relatively recent past. The impact of congestion mitigation approaches has been studied both analytically and empirically by researchers.

3.3.3.1 Modelling Approaches of Landside Congestion Management in Terminals

The most common modelling approaches employed in the literature are: linear programming, queuing theory and simulation modelling. A significant proportion of the literature on terminal logistics employs linear programming and queuing theory models (Lee *et al.*, 2010; Bugaric *et al.*, 2012; Van Asperen, Borgman and Dekker, 2013; Zhao and Goodchild, 2013; Wang *et al.*, 2018; Correcher, Alvarez-Valdes and Tamarit, 2019; Jos *et al.*, 2019) to identify the optimal efficiency, utilisation or financial outcome for given operational settings. Simulation modelling is also a frequently used analytical technique for terminal operations, supply chain and transportation modelling (Manuj, Mentzer and Bowers, 2009; Dragović, Tzannatos and Park, 2017; Opacic and Sowlati, 2017; Crainic, Perboli and Rosano, 2018; Kogler and Rauch, 2018).

Simulation modelling has increased in popularity since the turn of the century (Dragović, Tzannatos and Park, 2017). Some of the reasons behind this are the ability of the technique to represent the complex interactions taking place at a terminal (Huynh, 2009) and inherent uncertainty of terminal operations (Li *et al.*, 2019). Simulation is considered useful, particularly in industry settings, because of its ability to create a digital twin of physical infrastructure (Li *et al.*, 2019). Under controlled conditions, simulation can be a useful approach to better understand the behaviour of the system (Chang and Makatsoris, 2001), and in particular explore the effect of a limited number of variables (Manuj, Mentzer and Bowers, 2009). "What-if" scenarios can be developed and analysed (Crainic, Perboli and Rosano, 2018) while circumventing the additional costs and potential service disruption that a physical experiment or intervention would require. Simulation can also be useful for running reference projections which are, *"extrapolations from the past into the future under an assumption we know to be false: that things will continue to be done and to happen much as they have in the past […] they do not yield predictions of things to come, they predict what is unlikely to happen. They do this by showing how a system will break down if it were to continue to operate in the future as it did in the past*" (Ackoff, 1978). Finally, simulation modelling is conducive to supporting the development of tangible solutions for using insights gained from modelling (Dragović, Tzannatos and Park, 2017).

It is generally accepted in the literature that a more even distribution of truck arrivals at terminals can positively influence truck turnaround and waiting times. This relationship has been investigated by several researchers (Morais and Lord, 2006; Guan and Liu, 2009; Huynh, 2009; Do *et al.*, 2016). Modelling results generally point towards improvements in truck turnaround and waiting times as arrival patterns are spread and optimised (Huynh and Walton, 2008; Guan and Liu, 2009; Chen, Govindan and Yang, 2013; Li *et al.*, 2018; Torkjazi, Huynh and Shiri, 2018). Analytical approaches include queuing models (Guan and Liu, 2009; Chen, Govindan and Golias, 2013; Zhang, Zeng and Yang, 2018), simulation (Huynh, Walton and Davis, 2004; Sharif, Huynh and Vidal, 2011; Huynh, Smith and Harder, 2016; Li *et al.*, 2018), and linear programming (Zehendner and Feillet, 2014; Ambrosino and Caballini, 2015; Chen and Jiang, 2016; Torkjazi, Huynh and Shiri, 2018). Chen, Zhou, and List (2011) modelled truck arrivals using queuing theory and found a turnaround time reduction by as much as 60 minutes, from 100 to 40 minutes, in a container terminal. Chen, Govindan, and Yang (2013) optimisation model revealed a decrease in truck waiting times by as much as 93 minutes, from 103 to 13 minutes on average. Interestingly, some researchers identified that even small changes in arrival patterns can have a significant impact on turnaround times (Chen *et al.*, 2013; Zhao and Goodchild, 2013). Furthermore, the impact of optimal arrival patterns on turnaround times varies depending on the utilisation rate of the terminal (Chen, Zhou and List, 2011). Nevertheless, achieving a more even distribution of truck arrivals is not a trivial task.

3.3.3.2 Empirical Investigations of Landside Congestion Management in Terminals

The implementation and impact of landside congestion management approaches is investigated by a relatively smaller proportion of the literature (Giuliano *et al.*, 2008; Holguín-Veras *et al.*, 2011; Davies, 2013; Davies and Kieran, 2015; Bentolila *et al.*, 2016). Findings generally reveal significant variations in impact between implementations of similar methods, and a lack of defined criteria behind the choice of congestion mitigation approaches. A combination of extended terminal working hours and TAS implementation in the Los Angeles/Long Beach (LA/LB) port complex in the United States is investigated by Giuliano et al. (2007) who find low TAS usage rates. Subsequently, the PierPASS OffPeak pricing program was introduced as an additional landside congestion management approach. This congestion pricing program helped spread truck arrivals from almost exclusive daytime deliveries (Cambridge Systematics, 2009). In Sydney, Australia, following the implementation of a TAS, truck turnaround times decreased by approximately 30% and arrival punctuality increased from 72% to 95% in the first 12 months (Davies, 2013). In other cases however, congestion pricing and incentives appear to have had limited impact on shifting arrival patterns (Holguín-Veras *et al.*, 2011; Bentolila *et al.*, 2016). It is unclear from these studies what factors were considered in selection process for a landside congestion management approach.

The selection process for terminals landside congestion management approaches appears to be arbitrary and, often guided by costs or revenue generating potential for the terminals themselves. In this context, terminal appointment systems are one of the most favoured landside congestion management approaches. When faced with the challenge of reducing truck turnaround times under a certain threshold by environmental regulations, many terminals in the LA/LB port complex chose to implement a TAS rather than extend gate working hours due to cost considerations (Giuliano and O'Brien, 2007). With the introduction of non-compliance penalties for early, late or missed appointments, terminals have also benefited from TAS as the penalties have become important sources of income for terminal operators (Davies, 2013). This situation can create conflicting incentives for terminal operators as congestion may be perceived as an alternative to maintain high levels of equipment and infrastructure utilisation as well as generate additional revenue (Neagoe *et al.*, 2018). The disconnect between terminal and transporters' and supply chain outcomes is also a recurring pattern in the implementation process of TAS.

Implementations of TAS are often undertaken by terminals with little or no consultation with the end-users of the systems. This approach may cause frustration and additional costs for transporters. Some appointment systems set operating rules that are incompatible with the business requirements of transport operators. As a result, some carriers may persistently abuse or misuse the systems (Morais and Lord, 2006). The additional workload incurred by appointment management can also increase transporters' administration costs. Appointment compliance challenges due to travel times variability also increases the risk and cost of penalties (Davies, 2009). One of the main consequences of the lack of consultation with TAS users is the low system adoption, if system use is optional (Giuliano and O'Brien, 2007), or increasing penalties to enforce compliance with the system's rules. Consequently, the effectiveness of appointment systems can be decreased, or congestion and mitigation costs can be simply shifted from terminal operators to transporters.

The review of the relevant literature on the role of information systems in landside congestion management has highlighted that several tools and techniques, both novel and more established, have great potential in addressing congestion. However, the majority of insights and evidence come from experimental research and are not easily translated into practical outcomes. Empirical investigations on implementations of congestion mitigation mechanisms have produced inconsistent results. Furthermore, two of the most influential and highly cited papers in the domain of landside congestion management (Giuliano & O'Brien, 2007; Morais & Lord, 2006) have highlighted the ineffectiveness of appointment systems and the challenges faced by practitioners in implementing these systems. In spite of the fact that these papers are more than a decade old, the extant research literature has, to date, failed to answer to the question of how theoretical benefits, derived from congestion mitigation derived analytically, can be implemented and achieved in practice.

The next section discusses the research literature on 'wicked' problems their features and structuring approaches.

3.4 Wicked Problems, Participatory Design and Information Systems

This section explores the research literature on information and digital tools in the context socio-technical systems. The lens of 'wicked' problems is considered as a conceptual tool for a holistic understanding of socio-technical systems. The research literature on participatory design provides the methodological framework for investigating socio-technical systems and is sensitive to the existing and potential role of information and technological artifacts. Finally, the role of information systems in socio-technical systems and their application and impact in supply chains are explored.

3.4.1 Wicked Problems and Structuring Approaches

'Wicked' problems, as described by Rittel and Webber (1973), are issues characterised by a plurality of perspectives on the problem, stakeholder objectives and potential problem resolutions. The multitude of perspectives on a problem make it difficult to define it and consequently act. In fact, one of the key challenges in resolving 'wicked' problems is formulating the problem. Importantly, the initial problem may be a symptom of another problem. Consequently, approaching the problem at a low abstraction level may generate repercussions in other areas or limit the courses of action available to tackle the higher-level problem. A further complication is added by the fact that stakeholders tend to view and identify problems at a level lower than them. The objectives of stakeholders play an important role in the choice of problem explanations and courses of action viewed as most suitable. Unsurprisingly, conflicting objectives between stakeholders often yield incompatible views on problem resolution (Rittel and Webber, 1973). Problems had been previously addressed using quantitative operations research methods such as optimisation and queuing theory. The characteristics of wicked problems have also been defined in response to the perceived inadequacy of traditional, quantitatively driven, operations research approaches.

The quantitatively-driven approaches that were traditionally employed to address issues in organisations were found ill-equipped to address their social problems (Kirby, 2007; Smith and Shaw, 2019). The reason behind the inadequacy of quantitative approaches lies in their assumptions of problems and organisations, mainly, that problems have a definitive formulation and a single objective that can be attained through a unidimensional optimisation process driven by a single decision maker, consensus is assumed, and organisational interactions are depoliticised (Mingers and Rosenhead, 2001; Smith and Shaw, 2019). Philosophically, many of these assumptions were rooted in the tendency of quantitative approaches to control workplaces and responses and the suppression of "*open discussion and consideration of ends and values in favour of a technical selection of efficient means*"(Mingers, 1992 in Kirby, 2007). Therefore, approaches that were more closely aligned to the types of problems encountered in real-life situations were required to overcome the perceived disadvantages of quantitative operations research techniques.

Qualitative approaches to addressing problems encountered by organisations highlighted that problems are socially defined and dependent on the multiplicity of perspectives and the power relations amongst stakeholders. The stakeholders' perspectives are relevant in defining the problem situation. Qualitative approaches reject reductionism, and optimisation of individual parts, and manage the inherent complexity of problems, seeking the emergent features of systems (Smith and Shaw, 2019). The inclusion of multiple stakeholders is therefore important to jointly define problem situations. Knowledge regarding different perspectives can be elicited by consultants positioning themselves either as experts or facilitators. Expert modes are closely aligned with the quantitative operations research approaches where problems are independently formulated in ways that lends them to optimisation modelling. Alternatively, in the facilitator mode, consultants develop models of problem situations through participation and interactions by sharing situational knowledge to build joint definitions and problem resolutions (Franco and Montibeller, 2010). Power relations amongst stakeholders play a key role in determining the overall strategy in addressing problems. The political feasibility of resolution is primarily dependent on the power structures amongst stakeholders (Eden and Ackermann, 2004). Therefore, if power is concentrated, authoritarian approaches can be effective in generating outcomes. If power is dispersed and contested amongst participants, competitive approaches may be most suitable, while if power is dispersed and not contested, collaborative approaches are recommended (Roberts, 2000). Qualitative approaches to 'wicked' problems present a series of advantages when compared to quantitative approaches.

Qualitative approaches to identifying problem resolutions are often more suitable for dealing with 'messy' problems, primarily because of the assumptions made. Both hard and soft data are used and integrated in defining the problem situation, reducing the overall data requirements. Problem resolutions primarily seek to satisfice stakeholders rather than identify trade-offs for optimisation, often incorporating uncertainty and facilitating bottom-up planning. Importantly, people are treated as active and engaged subjects while their objectives and potential conflicts are clarified (Rosenhead, 2013). Whilst methods such as soft-systems methodology (Checkland and Poulter, 2010), strategic options development and analysis (Eden and Ackermann, 2001), strategic choice approach (Friend and Hickling, 2005) or facilitated system dynamics (Franco and Montibeller, 2010) have been developed and have been widely used, methods are often combined into *multimethodologies* "*…that deliberately seek to combine together a range of methods* […] *in order to match the richness of the problem situation…*" (Mingers and Rosenhead, 2004).

Landside congestion management appears to exhibit some features characteristic of 'wicked' problems. Multiple stakeholders are affected by the consequences of congestion (see Section 3.3.2). Stakeholders likely have diverging and even conflicting interests. The landside congestion management approaches proposed by stakeholders are likely to be aligned with their individual objectives and can be in direct contradiction with the objectives and incentives of other stakeholders. there is no clear and obvious 'solution' to the problem. Several potential mechanisms may be used to mitigate congestion. The choice of approach is also dependent on the lens chosen to analyse the problem – if an economic or utility lens is used to analyse the potential approaches to mitigate congestion, the proposed solution is likely to involve market-based mechanisms. The concept of 'wicked' problems and the features of resolution approaches provide a useful lens for understanding the factors conducive to the appearance of congestion and mitigation strategies in an integrated, holistic manner.

The next section discusses the socio-technical systems perspectives and participatory design.

3.4.2 Socio-Technical Systems and Participatory Design

This subsection explores the central tenets of socio-technical systems and focuses on participatory design as an approach to integrate socio-technical perspectives in situations where perspectives and objectives do not necessarily align.

3.4.2.1 Socio-Technical Systems

Socio-technical Systems emerged at the Tavistock Institute emphasising the idea that technology should not be the controlling factor in the work environments where they are implemented, rather both human and technological considerations should jointly drive the design of new work systems (Mumford, 2006). Importantly, *"[a] socio-technical perspective encourages one to challenge to related sets of views: first, that human beings are error-prone, unreliable agents, resistant to change, that ideally should be designed out of systems as soon as this is technically feasible and can be afforded; and second that when they cannot be designed out humans need to be managed exclusively through Tayloristic systems of command and control*" (Clegg, 2000). Socio-technical perspectives are closely aligned with action research which views the system of people and technology within organisations and the interaction between them as a complex whole that cannot be factored (Baskerville, 1999). In action research, organisational change is driven by the researcher as a way to improving the immediate problem situation and the theoretical base in the area of interest (Checkland and Poulter, 2010) Multiple approaches encompass socio-technical principles, such as soft-systems methodology (Checkland, 2000), cognitive systems engineering (Hollangel and Woods, 2005). In design of information systems and technology artefacts, socio-technical principles have primarily influenced human-cantered design (ISO, 2010).

In human-centred design designers, researchers and users collaborate and learn from one another with the goal of developing products and services aligned with the users' needs, practices and preferences (Steen, 2011). Human-centred approaches also attempt to relax some of the assumptions of more traditional systems development methods. Three key assumptions addressed are: (1) that the systems developed will tackle problems that are well defined, (2) individuals solve problems rationally, and independently of social and political contexts and (3) that objectives and goals can be defined early in the development process. As a result of these assumptions, systems' design can be primarily driven by technical imperatives which can fundamentally constrain work processes (Gasson, 2003). Human-centred design therefore primarily advocates for flexible designs that integrate users in the design process, is less technology-centric, and concerned with the interaction between explicit and implicit knowledge (Gasson, 2003). Human-centred approaches vary on two key dimensions: the extent of user involvement and the research and design orientation (Steen, 2011).

The research and design orientation concerns the focus on describing existing or past situations versus exploring alternative future scenarios (Haddon and Kommonen, 2003). The involvement of users in the design process can range from informative to participative (Kushniruk and Nøhr, 2016). On the one end of the spectrum, users can be consulted with regards to their existing workflow and perceived needs. Their responses can then be incorporated by developers in the designs of the systems, as well as informing the evaluation and subsequent changes of systems. People's behaviours can also be observed in their work environment and these findings can be translated into specifications for technology products (Beyer and Holzblatt, 1998). Designers and researchers engage users at their workplace, while working, study and redesign tasks by changing role structures or automating tasks. User-centred design (Norman, 2013), empathic design (Koskinen and Battarbee, 2003) and contextual design (Beyer and Holzblatt, 1998) are examples of approaches in which users inform the systems' development process. An important assumption of user-centred and contextual design is that the outcome resulting from using the approach is a technology artefact. This is primarily due to the fact that the development is primarily conducted by designers, which is one of the main criticisms of these approaches (François *et al.*, 2017).

On the other end of the spectrum, users can participate along with designers and researchers in the design process itself, developing and discussing ideas, generating mock-ups and prototypes and experiencing envisioned work scenarios (Kushniruk and Nøhr, 2016). Users not only have a voice but also a say in the outcome of design processes, which are not restricted to technology artefacts. Approaches that consider users as participants in the design process include co-design (Sanders, 2000), lead-user approach (Von Hippel, 2005), and participatory design (Ehn, 1993).

3.4.2.2 Participatory Design

Participatory design originated from Scandinavian union negotiations in the 70s on technology implementation in the workplace (Steen, 2011). Participatory design is rooted in the socio-technical tradition where the empowerment of workers for individual decision making was one of the key issues addressed (Trist and Emery, 2005). Participatory design stands in an opposition to the rationalist approaches of workplace transformation from two perspectives, political and theoretical. From a political perspective, rationalist approaches reduce workers' influence on workplace changes. From a theoretical perspective, the knowledge of workers is situated in interpretations, practices and artefacts and therefore cannot be decontextualised (Spinuzzi, 2005). Consequently, participatory design is grounded on principles of democracy, mutual learning and co-realisation (Bratteteig *et al.*, 2012).

In more recent times, participatory design has been used in information technology implementations. The participatory design process is concerned with giving voice to those who need it (Kushniruk and Nøhr, 2016). This is particularly required in technology implementations as the boundaries of engagement are often predetermined (Wilson and Howcroft, 2003). Furthermore, those affected by technology are not necessarily involved in the decision-making process regarding the technology's features and functions. Technology is not neutral and transforms the practices where it is introduced (Kanstrup and Bertelsen, 2013). Participatory design can be employed to involve those affected by change and to help achieve a more equitable implementation process.

Participatory design draws on a large variety of methods and techniques. At an individual level, ethnographic tools such as interviews and observation (Spinuzzi, 2005) can be used to capture perspectives and work practices. In group settings, participants can be brought together in workshops and engage in discussions facilitated by visualisation and graphics, 2D and 3D models (Brandt, Binder and Sanders., 2012), use cards to organise, categorise and prioritise ideas or build '*what-if*' provocations (Muller and Kuhn, 1993). As the design process progresses, participants can specify requirements collaboratively as well as prototyping and creating mock-ups. These techniques have been used in a range of applications.

Participatory design has been predominantly applied in the development of information systems in the healthcare sector (Pilemalm and Timpka, 2008; Pihkala and Karasti, 2016;

Østergaard, Simonsen and Karasti, 2018; Tang *et al.*, 2018). In this sector, the "fail fast and then iterate" philosophy, acceptable in consumer-oriented tasks, is not an acceptable given the clinical implications digital tools generally have (Wachter and Howell, 2018). Consequently, the use of participatory design has been motivated by the desire to design more effective and usable systems (Pilemalm and Timpka, 2008). Other applications of participatory design can be found in media (Kensing, Simonsen and Bodker, 1998), or ERP implementation (Pries-Heje and Dittrich, 2009). In logistics and supply chain however, there are few examples of participatory design use.

The next section reflects on the research literature on information systems with a focus on technological artefacts and embedded social processes as well as the sharing of information.

3.4.3 Information Systems

Information systems (IS) cover a broad range of terms often used interchangeably in various fields, leading to significant definitional ambiguity. Much of the definitional ambiguity appears to be a result of different conceptualisations of information systems: technological, social, socio-technical and process aspects (Boell and Cecez-Kecmanovic, 2015). Table 6 presents a few selected definitions highlighting the different perspectives and conceptualisations.

Table 6 Selected Definitions of Information Systems

Researchers	Information Systems (IS) Definitions
Alter (2008)	*"An IS is a system in which human participants and/or machines perform work (processes and activities) using information, technology, and other resources to produce informational products and/or services for internal or external customers."*
Symons (1991)	"*The system utilises computer hardware and software; manual procedures; models for analysis, planning, control and decision making; and a database. The emphasis is on information technology embedded in organisations.*"
Laudon and Laudon (2007)	"*Interrelated components working together to collect, process, store, and disseminate information to support decision making, coordination, control, analysis, and visualisation in an organisation.*"
Huber, Piercy and Mckeown (2007)	"*An organised collection of people, information, business processes, and information technology designed to transform inputs into outputs, in order to achieve a goal system is a human activity (social) system which may or may not involve computer systems.*"
Lee (2001)	"*The information systems field examines more than just the technological system, or just the social system, or even the two side by side; in addition, it investigates the phenomena that emerge when the two interact.*"
Falkenberg *et al.* (1998)	"*An information system is a subsystem of an organisational system, comprising the conception of how the communication- and information-oriented aspects of an organisation are composed (e.g. of specific communicating, information-providing and/or information-seeking actors, and of specific information- oriented actors) and how these operate, thus describing the (explicit and/or implicit) communication-oriented and information-providing actions and arrangements existing within that organisation.*"
Davis (2000)	"*A simple definition might be that an information system is a system in the organisation that delivers information and communication services needed by the organisation […] The information system or management information system of an organisation consists of the information technology infrastructure, application systems, and personnel that employ information technology to deliver information and communication services for transaction processing/operations and administration/management of an organisation.*"

Symons' (1991) and Laudon and Laudon's (2007) conceptualisations of IS emphasises heavily the technology aspects. This conceptualisation appears to have been adopted, explicitly or implicitly, by a large proportion of supply chain and maritime logistics researchers (e.g. van Baalen, Zuidwijk and van Nunen, 2008; Gonzálvez-Gallego *et al.*, 2015). Consequently, the term IS is often used interchangeably with information technology (IT). This perspective attributes agency to the technology therefore prompting investigations on the impact of IS in organisations, but can also underrepresent the importance of social and socio-technical interactions (Boell and Cecez-Kecmanovic, 2015).

Other researchers such as Huber, Piercy and Mckeown (2007) or Lee (2001) conceptualise IS as the technical and social aspects, as well as the interactions amongst these. From this perspective, IT is a component of these systems, however it is no longer the focal point. A distinction can therefore be made between digital data and digital technologies (Inkinen, Helminen and Saarikoski, 2019) as well the ways in which these are used in organisations. Alter (2008) emphasises the processes and activities that produce informational products in organisations whilst maintaining the focus on the human and technology components of the system. This conceptualisation questions the assumption that IT is required for IS innovation therefore potentially allowing deeper understanding of organisational phenomena (Alter, 2008). Alter's (2008) definition of IS will be used throughout this research. IS therefore encompasses both technology artefacts and information.

3.4.3.1 Technology Artefacts and Social Processes

Information technology represents the technical side of information systems, comprising of electronic devices, computers and software programs (Laudon and Laudon, 2007). A key discussion point in the research literature regards the agency of technology artefacts and consequently their impact on human activities. Some researchers assume technological determinism in which digital tools actively affect social interactions through the embodiment of rules, restrictions and monitoring (Zuboff, 1988; Boudreau and Robey, 2005). Under this perspective, technology is a relatively autonomous driver for change in organisations with relatively predictable outcomes (Cascio and Montealegre, 2016). This view appears consistent with the research literatures investigating the role of information technology in supply chains and ports (see Section for 3.4.3.3). Other researchers highlight the social nature of technology.

Technology can also be considered "*a socio-technical assemblage*" (DeSanctis and Poole, 1994; Markus and Silver, 2008). From this perspective, technology is a product of social processes, which mediates human action and can produce a variety of social meanings (Orlikowski, 1992). Social meanings are attributed in the context of use, even as form and function remain constant (Orlikowski, 1992). Technology artefacts may have several affordances which can be defined as "*possibilities for goal-oriented action afforded to specified user groups by technical objects*" (Markus and Silver, 2008) However, whilst technology artefacts have built-in functions and affordances, the potential use and the actual use may differ (Balci, Rosenkranz and Schuhen, 2014). The actual uses can be influenced by the way in which the artefacts were implemented or the unintended consequences of the introduction of the digital tools.

The success of implementing digital tools may be affected by the differences amongst actors in terms of technological incompatibly, conflicting operational practices or organisational culture (Denolf *et al.*, 2015). Such differences may limit the scope of implementation or its adoption. Project management, including top-management support and the involvement of and communication with users and stakeholders can also affect the outcomes of IS introduction in supply chains (Hawley, 2016; Denolf *et al.*, 2018) by providing direction and supporting the project development. Furthermore, the importance of monitoring and evaluating systems' performance to address issues but also alleviate concerns is also highlighted by researchers (Denolf *et al.*, 2018; Reitsma and Hilletofth, 2018). At an individual level, much of the research has centred on DeLone's and McLean's information system success model (1992) that considers the information systems', data and service quality as primary determinants for the systems' use and satisfaction. These factors can have an impact both on the individual and subsequently on the organisation (Petter, Delone and McLean, 2013; Yeoh and Popovic, 2016). Nonetheless, other factors may contribute to the failure of digital tools implementations to produce the originally intended outcomes.

The unintended consequences of IS have been explored to understand the way systems are used in practice. Unintended consequences have primarily been researched in the health informatics environment (Campbell *et al.*, 2006; Coiera, Ash and Berg, 2016; Kuziemsky, Randell and Borycki, 2016). Understanding unintended consequences is critical in healthcare as the "fail fast and then iterate" philosophy can have profound clinical outcomes (Wachter and Howell, 2018). Unintended consequences can range from reduced redundancy due to increased dependence on technology coupled with paper persistence for transferring information between systems that are not digitally linked (Campbell *et al.*, 2006; Coiera, Ash and Berg, 2016). Importantly, workplace processes can be decontextualised (e.g. by transforming synchronous face-to-face interactions into asynchronous digital interactions) (Kuziemsky, Randell and Borycki, 2016) which can open the way for potentially hazardous workarounds.

3.4.3.2 Information - The Difference That Makes a Difference

This section briefly discusses the information in the context of information systems. Information is a concept that is relatively poorly defined in IS research (McKinney and Yoos, 2010). The research literature does however distinguish between two main perspectives, objective or subjective, on information aligned with the philosophical stance taken by the researchers.

From an objective perspective, theories such as the mathematical theory of communication (Shannon and Weaver, 1963) view information as a reduction of entropy or uncertainty in a system. In a similar vein, Dretske (1981) defined information as the regularity between the sings and the objects while MacKay (1969) links information with the potential change in behaviour. One of the commonalities between these theories is that information and its value is independent of the observer (McKinney and Yoos, 2010). Particularly in the case of the mathematical theory of communication, the value of information is a measurable reduction in uncertainty. If information is viewed from an objective perspective, the addition of information in a system is expected to have an impact on the system. Although largely unstated, this objective perspective appears to be prevalent in the academic literature on supply chains and the role of information technology and information sharing (see Section 3.4.3.3.2 for a more detailed review).

From a subjective perspective, information is "*difference that makes a difference*" (Bateson, 1973 in McKinney and Yoos, 2010). This conceptualisation of information highlights the importance of perception for subjects or systems (McKinney and Yoos, 2010). Thus, it is not only necessary for the information to reduce uncertainty, but in order to produce change, the information should also be perceived as relevant by the observer. In other words, the information has to have meaning for the observer. This perspective also acknowledges that individual observers may attribute different meanings to the same piece of information. An important part in the discussion of "*difference that makes a difference*" is the fact that information in meaningful context become knowledge. However, as Nonaka and Takeuchi (1995) discuss in their seminal research, knowledge can be '*explicit*', transmissible through the use of language, and '*tacit*', difficult to formalise, communicated and highly contextual. Thus, it is likely that not all information is embodied in formal symbols and language. Information in this context is integrally intertwined with the generation of meaning.

3.4.3.3 The Role of Information Systems in Landside Congestion Management

Information systems have been researched and discussed extensively in the context of supply chains and ports. Information is considered ''*the glue that holds a supply chain together*''(Romano, 2003) and a logistics resource, substituting inventory whilst technology enabled the geographical dispersion and distribution of logistics activities (van Baalen, Zuidwijk and van Nunen, 2008). Consequently, many researchers have explored the potential roles information and digital tools can play in supply chains and logistics as well with the impact these have on organisational and supply chain performance.

Information systems, particularly through technology tools, have played a significant role in the management of congestion whether in traffic systems or in marine terminals. Existing technologies have enabled traffic congestion mitigation approaches through Machine Vision and Radio-Frequency Identification (RFID) (Nayak and Katakiya, 2019) as well as through digital platforms supporting congestion pricing programmes (Lehe, 2019). Furthermore, recent technology developments have shown great promise in potentially addressing congestion through the coordination of autonomous vehicles (Ha *et al.*, 2020; Zhong, 2020), the Internet of Things (IoT) or Internet of Vehicles (IoV) (Paranjothi *et al.*, 2020; Paranjothi, Khan and Zeadally, 2020). Similar developments can be observed in the realm of landside congestion management in marine terminals.

The research literatures exploring the role of information and digital tools in supply chains and marine terminals appear to rely on underlying assumptions consistent with what the information systems literature considers technological and informational determinism (Orlikowski, 2009). However, the role information systems can be also explored from a socio-technical systems perspective (see Section 3.4.3).

3.4.3.3.1 The Role of Digital Tools

Technologies such as remote sensing, networked embedded sensors operating in the Internet of Things (IoT) (Scholz *et al.*, 2018), blockchain (Jabbour *et al.*, 2020) artificial intelligence

(AI), machine learning and deep learning as well as big data and cloud computing (Müller, Jaeger and Hanewinkel, 2019) are perceived as solutions to many of the challenges faced by modern supply chains. These technologies are perceived to have transformative capacity on supply chains and the potential to generate significant yield and quality improvements, enhance customer experience and facilitate technology transfer (Watanabe, Naveed and Neittaanmäki, 2018). Digital tools are often enablers and facilitators for communication and task automation in organisations and supply chains. Infrastructural technology such as Global Positioning Systems (GPS) , Radio-frequency Identification (RFID) and Optical Character Recognition (OCR), have enhanced data capture throughout supply chains and port spaces enabling real-time visibility and transactional tasks automation (van Baalen, Zuidwijk and van Nunen, 2008; Heilig and Voß, 2017; Jacobsson, Arnäs and Stefansson, 2020).

The quality of information in terms of accuracy, accessibility, adequacy and timeliness have been improved by novel technology tools (DeGroote and Marx, 2013; Ruel, Ouabouch and Shaaban, 2017). Information sharing and communication is also facilitated by various technology tools (Wu *et al.*, 2006; Fawcett *et al.*, 2011). One notable technology is Electronic Data Interchange (EDI) which allowed the harmonisation and digitalisation of information exchange amongst stakeholders in the logistics space (Heilig and Voß, 2017). Port Community Systems have built on these information exchange capabilities to reduce information access and communication costs as well as to enhance the quality of information shared among stakeholders (Carlan, Sys and Vanelslander, 2016; Inkinen, Helminen and Saarikoski, 2019). Digital tools have also been used in ports to address congestion.

Two approaches to mitigate congestion (discussed in more detail in Section 2.3.3) are automated gate systems and terminal appointment systems. Automated Gate Systems rely heavily on RFID and OCR to automate the interaction with landside transporters and reduce document processing times (Heilig, Lalla-Ruiz and Voß, 2016). Building on these systems, Terminal Appointment Systems (TAS) create time slots for truckers to deliver and pick-up cargoes facilitating visibility amongst stakeholders (Huynh, Smith and Harder, 2016). The ultimate aim of both approaches is to enhance operational efficiency. In this context, it is important to understand the rationale behind the claims on the potential impact of information systems.

Digital tools are perceived to have the potential to improve efficiency (Prajogo and Olhager, 2012; Gonzálvez-Gallego *et al.*, 2015; Gunasekaran, Subramanian and Papadopoulos, 2017) and generate competitive advantage in organisations and supply chain (Fosso-Wamba *et al.*, 2015; Gunasekaran, Subramanian and Papadopoulos, 2017). In forestry supply chains, digital tools are perceived to have the potential to enable real-time end-to-end visibility, increase delivery accuracy and limit inventory costs (Watanabe, Naveed and Neittaanmäki, 2018).

The theoretical support underpinning these statements can be traced back to the resource-based view (RBV) (Barney, 1991). The RBV distinguishes between tangible and intangible resources with long-term production capabilities, under the control of the firm, that can be produced internally or sourced externally (Barney, 1991). A key aspect is that the strategic importance of resources is derived from their availability, or scarcity (Clemons and Row, 1991) and their imperfect imitability. One consideration is the increased competitive advantage which is derived from controlling heterogeneous resources that differentiate the firm from its competitors. Competitive advantage is typically defined as the ability to consistently outperform the average industry return on investment (Porter, 1985). Consequently, the RBV has been adopted by a large proportion of researchers investigating the role and impact of technology on firms' performance (Bhatt and Grover, 2005; van Baalen, Zuidwijk and van Nunen, 2008; Ye and Wang, 2013).

However, other researchers have cast doubt on the potential of information systems to generate competitive advantage even within the RBV context. Digital tools do not have the characteristics of heterogeneous strategic resources when considered in isolation (Prabir *et al.*, 2014). Most technology tools are relatively easily imitable and entry barriers are low as the costs for new software and infrastructure technology have steadily decreased (Carr, 2003). Furthermore, some researchers claim that technology by itself is insufficient to generate superior performance due to its widespread availability and access (Carr, 2003; Gonzálvez-Gallego *et al.*, 2015). Other researchers argue that technology in itself is not a direct contributor to value creation. According to this view, firms can achieve competitive advantage by better understanding how to integrate digital tools in their businesses (Huo, Han and Prajogo, 2016). Therefore, given the lack of agreement amongst researchers on the role of digital tools in organisations and supply chain, the empirical impact of information systems have had on organisational and supply chain performance is explored next.

Empirical support for the impact of digital tools on organisational and supply chain performance is mixed. Some researchers have found positive correlations between information technology investments and performance – whether financial or operational (Johnson *et al.*, 2007; Sanders, 2007; Ye and Wang, 2013; Gonzálvez-Gallego *et al.*, 2015). Others have found no significant relationship between technology investments and organisational performance (Jin, 2006; Fawcett *et al.*, 2007; Albani and Dietz, 2011; Sanders, Autry and Gligor, 2012). In fact, information systems implementations are still considered a high-risk investment for many organisations (Kutsch *et al.*, 2013). A recent survey of business executives highlighted that digital transformation risk was their top concern given that 70% of digital transformation projects fail to reach their goals (Tabrizi *et al.*, 2019) This has led researchers to posit the importance of considering the human element in the implementation and use of digital tools (Frankiewicz and Chamorro-Premuzic, 2020) and explore the socio-technical factors that influence the impact of information systems in organisations.

The literature on evaluating the impact of digital tools in landside congestion management is relatively scarce and shows mixed results (discussed in further detail in Section 2.3.3.2). Davies and Kieran (2015) found significant improvements in truck turnaround times at terminals in Sydney, Australia, following the implementation of a terminal appointment system (TAS). Giuliano and O'Brien (2007) found a limited impact of appointment systems in Los Angeles, United States. Beyond the terminal efficiency measures which measure the success and failure of digital tools in landside congestion management, researchers have also highlighted that appointment systems have implications, second order consequences. These include increased penalties and administration costs for transporters and decreased operational flexibility (Morais and Lord, 2006; Giuliano and O'Brien, 2007; Davies, 2009). Given the variations in outcomes between information systems implementations, it appears likely that a broader range of factors and their interactions contribute to the impact of information systems on organisations and supply chains.

The next section explores the role of information sharing in supply chains.

3.4.3.3.2 The Role of Information Sharing

In the context of supply chains, *information sharing* can be defined as "*access to information residing in another company in the supply chain*" (Jonsson and Mattsson, 2013). Information sharing can develop to address situations in which "*information asymmetries arise between those who hold that information and those who could make better decisions if they had it*" (Connelly *et al.*, 2011). Information asymmetry can be defined as the situation where one party in an exchange has more information about some aspects of an exchange than others (Tong and Crosno, 2016). Information asymmetry may arise for several reasons such as the existence of private information, which can be privileged or proprietary (Ecker, van Triest and Williams, 2013), the unequal distribution of information in an environment (Stiglitz, 2002) or due to purposely hidden information (Bergh *et al.*, 2019). Asymmetry can be addressed through incentives to gather and disclose information, pre-commitment to certain actions, monitoring and rewards and information intermediaries (Bergh *et al.*, 2019).

"*Information sharing is often considered as a generic cure for supply chain ailments*" (Sahin and Robinson, 2002). The information sharing research literature tends to be primarily descriptive of the antecedents, barriers, dimensions and outcomes of information sharing. Trust is perceived as a key antecedent to information sharing (Fawcett *et al.*, 2007; Kembro, Näslund and Olhager, 2017; Mora-Monge *et al.*, 2019). The level of connectivity within and between organisations is also an important antecedent of information sharing (Fawcett *et al.*, 2007). Connectivity is often perceived from the technological standpoint, referring to the ability to share information using technological means. Barriers to information sharing include unfair allocation of benefits, lack of common performance indicators and common goals as well as confidentiality concerns (Kembro, Näslund and Olhager, 2017). Silo-ed approaches as well as "*never considering sharing information in the first place*" (Shaw, Grainger and Achuthan, 2017) were also impeding factors to information sharing. Interestingly, with public entities operating alongside private organisations, one barrier to information sharing was the desire to avoid unintended consequences (Shaw, Grainger and Achuthan, 2017).

Information sharing, together with contracts, negotiations and auctions, are mechanisms that support the instantiating coordination mechanisms between supply chain stakeholders (Vosooghidizaji, Taghipour and Canel-Depitre, 2020). "*A coordination mechanism is a* [set of rules] *for which the implementation of optimal strategies by decentralised, self-interested parties may lead to an improved outcome and neither violates individual rationality nor budget balance for the participating parties*" (Albrecht, 2010). Information sharing can increase supply chain visibility (Soroor, Tarokh and Shemshadi, 2009; Huo, Han and Prajogo, 2016) and facilitate coordination by assisting in decision-making and facilitating quick responses to changes (Tong and Crosno, 2016). However, whilst information sharing may increase visibility and transparency, it may not guarantee information accuracy nor the alignment of objectives between supply chain stakeholders (Mason and Villalobos, 2015).

The empirical support for the positive impact of information sharing on firms' and supply chain performance is more consistent. Ye and Wang (2013) identified a positive relationship between information sharing and cost efficiency and customer responsiveness. These relationships are supported by Fawcett *et al.*(2011). Li *et al.* (2012) found a positive relationship with improved market position and sales volumes. Huo et al. (2016) found that external information integration was positively related to the operational efficiency of firms but had limited impact on service quality. Conversely, internal information integration was positively related to service quality but had limited impact on the firms' internal operational efficiency (Huo, Han and Prajogo, 2016). Information sharing was found to have a positive impact on product quality (Carr and Kaynak, 2007), and improve the operational performance of companies by enhancing resource usage, output and flexibility (Yigitbasioglu, 2010). Nevertheless, some researchers have found a non-significant relationship between information sharing, particularly of sharing forecasts, and performance (Forslund, 2007; Sezen, 2008). Others support the argument that the effectiveness and efficiency of information sharing approaches are in fact dependent on the context in which they are deployed (Tong and Crosno, 2016).

The research literature on information sharing provides an extensive description of the antecedents, barriers, dimensions and outcomes of implementing information sharing. It remains unclear however whether and how an understanding of aspects new information sharing can be used to initiate new information sharing or maintain continuity of existing practices. One important aspect regarding the initiation of information sharing relates to information asymmetry between supply chain stakeholders with regards to the information collected and available in the supply chain. An important latent assumption made by some researchers investigating information asymmetry is the awareness of the existence of information in the supply chain.

The next section aims to detail the narrative around the research literatures analysed, highlighting the research problem and questions of this thesis.

3.5 Reflections on the Research Problem and Questions

This chapter has described the key research literatures pertaining to this research: port-centric supply chains, landside congestion management, information and digital tools in the context of socio-technical systems. The research problems emerging from the synthesis of the existing research literatures are considered from the conceptual, methodological and substantive perspectives. The research questions are subsequently formulated.

At a conceptual level, the research in the logistics space tends to be segmented into discrete research foci. These foci can centre either on different organisation types (e.g. terminal operators) or transport modes (e.g. land- or sea-based). The problems defined within these research foci are often addressed with an efficiency or cost focus (Andersson *et al.*, 2010; Ambrosino and Caballini, 2015; Gansterer and Hartl, 2018). Some researchers have also subscribed to more holistic perspectives which recognise that logistics challenges can be affected by other logistics operations (Van der Horst and De Langen, 2018) or supply chain elements (Andersson, 2011). Holistic approaches recognise the existence and potential impact of inter-relationships amongst logistics and supply chain elements.

The importance of a holistic perspectives in understanding inter-relationships amongst logistics and supply chain elements and their impact is highlighted in the research literature in two ways: from a problem structuring view, the definitions of problems formulated within a research focus may be artificially bounded and not shared across organisations. This may in turn affect the perceived courses of action available to address the problem. Furthermore, the consequences of implementing solutions may not be fully captured, particularly those consequences occurring beyond the boundaries of the problem formulation (Rosenhead, 2013; Smith and Shaw, 2019); from an integration view, approaches considering multiple elements of a supply chain and their inter-relationships can reduce uncertainty (Huang, Yen and Liu, 2014), enhance performance, competitive advantage (Schoenherr and Swink, 2012).

The research on the role of information systems (IS) in logistics and supply chain has tended to focus on the organisational level. This focus is largely supported by the resource-based view (RBV). Consequently, IS are considered communication and automatization enabler and ultimately drivers for increased organisational efficiency and competitive advantage (van Baalen, Zuidwijk and van Nunen, 2008; Heilig and Voß, 2017). Significant focus has been placed in supply chain and logistics research in understanding the role digital tools can play. In these research domains, empirical investigations which explore the use of digital tools in practice are relatively rare. Often, however, the attributes of the digital tools are not considered in relation to the issues they are expected to address. The research literature on information sharing provides extensive description of the antecedents, barriers, dimensions and outcomes of implementing information sharing. It remains unclear however, whether and how an understanding of these aspects of information sharing can be used to initiate or maintain information sharing practices.

The challenges described above also manifest in the context of landside congestion management at marine terminals. Contemporary approaches to understanding and mitigating congestion, both in the research literature and in practice, have primarily focused on individual components of the supply chain rather than on how these components interact. As a result, these approaches are often disconnected from an awareness of many of the underlying factors that contribute to the emergence of congestion. Furthermore, many congestion mitigation approaches tend to prioritise technical solutions that address narrowly defined technical, economic and/or regulatory metrics. For example, digital tools in the form of terminal appointment systems (Huynh, Smith and Harder, 2016; Schulte et al., 2017) and automation technologies (Heilig and Voß, 2017) are one of the preferred landside congestion management approaches. The use of digital tools for landside congestion management seems often motivated by terminal efficiency or cost considerations (Chang Guan and Liu, 2009) rather than an understanding of the tools' roles in mitigating congestion. Evidence in the research literature and practice points towards how infrastructure, technology and regulatory instruments can impact on congestion, as measured through narrowly defined metrics, at individual points of the supply chain. However, the extent to which this may be partly a consequence of shifting the problem to other parts of the supply chain remains unclear, as does the mechanism through which congestion mitigation approaches are chosen. A better understanding of the factors contributing to the appearance of congestion and of suitable mitigation mechanisms may help improve the effectiveness of approaches aimed at managing congestion.

At a methodological level, the approaches most frequently used in the research literature analysed tend to be quantitative, centred on surveys or analytical modelling. These approaches are effective at improving understanding on existing issues and challenges and illustrating potential optimal outcomes. However, they provide limited guidance as to how mechanisms or digital tools can be implemented to address the challenges identified and to achieve the modelled optimal outcomes. Furthermore, the objective assumptions of quantitative approaches may limit the variety of perspectives that can be adopted in analysing a problem. Participatory design is an approach that can facilitate improved understanding of a problem and the design and implementation of contextually-relevant solutions, including digital tools. Participatory design has been previously used in the development and implementation of IS in healthcare (Østergaard, Simonsen and Karasti, 2018; Tang *et al.*, 2018) or enterprise resource planning systems (Pries-Heje and Dittrich, 2009). Although promising, participatory design has yet to be used in the context of landside congestion management.

At a substantive level, an overwhelming proportion of research in landside congestion management has been focused on container terminals (Chen and Jiang, 2016; Torkjazi, Huynh and Shiri, 2018). In Australia, landside congestion management has received little attention even in container terminals (e.g. Davies and Kieran, 2015). The research on landside congestion management in bulk cargo marine terminals is limited and, to date, no research has investigated landside congestion management in bulk marine terminals for forest products.

The following research questions were therefore formulated to address the research problems identified:

RQ-1. *What congestion factors, their interrelationships, and implications can be identified and understood?*

RQ-2. *How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?*

RQ-3. *What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?*

The next chapter provides a detailed description of the methodology used in this research to answer the research questions formulated in this chapter..

Chapter 4 Methodology

4.1 Introduction

The previous chapter has described the key research literatures pertaining to this research: on port-centric supply chains, landside congestion management, and '*wicked*' problems. Reviewing the relevant research literatures led to the formulation of the three research questions:

RQ-1. *What congestion factors, their interrelationships, and implications can be identified and understood?*

RQ-2. *How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?*

RQ-3. *What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?*

The methodology adopted in this research involved the conduct of three case studies using a participatory design approach. Each case study was focused on an Australian bulk-cargo marine terminal and its users' supply chains. The research strategy consisted of multiple case studies using a three-stage participatory design approach and deploying both qualitative and quantitative data collection and analysis techniques. The three stages were: exploration, design workshops and evaluation. This chapter is divided into the following sections:

- Section 4.2 discusses the research philosophy adopted in this research. A subjective ontology with an interpretivist epistemology were adopted for this exploratory investigation.
- Section 4.3 presents the research strategy which consisted of multiple case studies, each consisting of a three-stage participatory design approach and deploying mixed-method data collection and analysis techniques. The three stages of the participatory design approach were: exploration, design workshops and evaluation. Stage 1: Exploration aimed to provide a baseline understanding generated primarily from the analysis of qualitative data of the participants perceptions of congestion and factors contributing to it, as well as insights into congestion impacts and potential mitigation mechanisms. Stage 2: Design Workshops to capture joint understanding of the participants' perceptions and facilitate the alignment of perspectives and the development of a common vocabulary amongst participants. The quantitative data collected in the previous stage were analysed using *simulation modelling* and *exploratory data analysis* techniques and the results were presented and discussed as part of the development of a common vocabulary. Furthermore, the workshops included a design component in which participants, using the common vocabulary, could develop congestion mitigation approaches for their supply chains. Finally, Stage 3: Evaluation aimed to explore the effectiveness of the participatory design process

on the participants' understanding of congestion and on the mechanisms, tools and techniques for its mitigation.[6]

- Section 4.4 provides a description of the three case studies included in this research. Each case centres on a bulk cargo marine terminal and the associated wood chips or log supply chains.
- Section 4.5 details the research procedures utilised for data collection. The case study selection is discussed first. Next, Stage 1: Exploration techniques are discussed. Qualitative data were collected through site visits and semi-structured interviews. Quantitative data consisting of truck arrival records from weighbridges and truck geo-positioning data were also collected. Stage 2: Design Workshops consisted of four workshops, minimum one per case, across the 3 case studies. Qualitative data emerging from the workshops was collected. During Stage 3: Evaluation, qualitative data were collected through semi-structured interviews. Quantitative data consisting of truck arrival records from weighbridges were also collected.
- Section 4.6 presents the research procedures utilised for data analysis. Qualitative data were analysed using grounded theory coding principles. Simulation modelling and exploratory data analysis (including statistical summarisation, statistical testing techniques and data visualisation) were employed in Stage 2: Design Workshops (to analyse data collected in Stage 1: Exploration) and in Stage 3: Evaluation. [7]
- Section 4.7 presents the iterative interpretive process adopted to produce the findings of this research from results. Next the approach adopted for discussing the results and emerging findings in relation to the research questions and the extant literature is discussed.
- Section 4.8 presents a summary conclusion for this chapter.

This investigation has been approved by the Human Ethics Research Committee (Tasmania) under ref: H0016718.

4.2 Research Philosophy

This section describes the research philosophy adopted for this investigation. Philosophical assumptions encompass the researcher's world view and view regarding the ways that knowledge can be generated (Trauth, 2001).The philosophy guided the overall research strategy choices and played key role in shaping the ulterior methodological decisions.

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[6] This section draws from Neagoe, M., Hvolby H-H., Taskhiri, M. S., Nguyen, H.-O. and Turner, P "What's the hold up? A participatory design approach to understanding and ameliorating congestion at an Australian marine terminal". Maritime Economics and Logistics, UNDER REVIEW

[7] This section draws from Neagoe, M., Nguyen, H.-O., Taskhiri, M. S., and Turner, P "Exploring the role of information systems in mitigating gate congestion using simulation: theory and practice at a bulk export terminal gate." In IFIP International Conference on Advances in Production Management Systems, pp. 367-374. Springer, Cham, 2018 and Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P (2019a). "Understanding the Impact of User Behaviours and Scheduling Parameters on the Effectiveness of a Terminal Appointment System Using Discrete Event Simulation." In: IFIP International Conference on Advances in Production Management Systems, Springer Berlin Heidelberg

4.2.1 Ontology

Ontology studies the nature of reality (Guba and Lincoln, 1989). Ontology grapples with issues regarding the construction of the empirical world either independently of observers, therefore objective, or through social interactions, therefore subjective (Orlikowski and Baroudi, 1991). Consequently, ontology governs the subsequent assumptions with respect to epistemology and methodology (Chua, 1986).

This research is an exploratory investigation into congestion and the role of information systems at bulk cargo marine terminal for forest products. In approaching this investigation, a subjective ontology was adopted utilising an interpretive epistemology. A subjective ontological position assumes a value-laden, socially constructed, dynamic reality and allows an in-depth exploration of a phenomenon from the perspectives of those involved (Yilmaz, 2013). Additional in-depth access to issues, data and people, can be secured, particularly when the researcher is perceived to attempt to make a valid contribution to the situation in the field (Walsham, 2006).

4.2.2 Epistemology

Epistemology refers to the assumptions regarding knowledge acquisition and construction (Cavaye, 1996). An interpretivist epistemology seeks to understand how practices and meaning are generated by norms and language shared by humans in an environment (Orlikowski and Baroudi, 1991). Importantly, the context of the phenomenon can be recognised and explicitly included as a relevant component of the phenomenon under study (Keen, 1991).

An interpretivist epistemology was adopted in this research given the subjective ontological position adopted for this research and the exploratory and qualitative nature of the research questions posed in this investigation. The researcher therefore becomes the research instrument (Yilmaz, 2013) while acknowledging his biases and the impact of prior knowledge on the investigation. The researcher can thus enter the field without theoretical concepts generated a-priori and allow for the emergence of such concepts while understanding and learning about the phenomenon.

In summary, a subjective ontology with an interpretivist epistemology were considered most appropriate for this investigation considering its exploratory nature. The next section presents the research strategy which consisted of multiple case studies in which a three-stage participatory design approach utilising mixed methods.

4.3 Research Strategy

This research aims to explore landside congestion and the role information systems can play in addressing congestion at bulk cargo marine terminals for forest products. To achieve this aim, the research strategy adopted consisted of multiple case studies in which a three-stage participatory design approach utilising mixed methods has been adopted. The three stages of the participatory design were: Stage 1: Exploration, Stage 2: Design Workshops and Stage 3: Evaluation.

This section includes an in-depth discussion on the use of multiple case studies (Section 4.3.1), the three-stage participatory design approach (Section 4.3.2) and mixed methods for data collection and analysis (Section 4.3.3).

4.3.1 Multiple Case Studies

This section provides a rationale for the choice of a multiple case studies research strategy. A case study approach allows the exploration of issues in real-life settings. Furthermore, multiple cases can overcome issues surrounding case idiosyncrasies. The lack of a framework to understand and approach congestion in marine terminals and the exploratory nature of this research meant that a multiple case studies approach was considered most appropriate for this research.

4.3.1.1 Case Study Research

Case study research is primarily concerned with gaining an in-depth understanding of a contemporary phenomenon (Yin, 2003) spatially and temporally defined (Miles and Huberman, 1994). Situations where the behaviours of participants cannot be easily manipulated (Cavaye, 1996) and where the contextual conditions of the problem and the boundary between the problem situation and its context are ill-defined (Yin, 2003) are conducive to the use of case studies. The phenomenon of interest can be studied in its natural setting, allowing the researcher to understand the complexity of the setting and the processes taking place in the field site (Benbasat, Goldstein and Mead, 1987). Case studies are especially useful when there is limited conceptual development of phenomenon of interest, the existing perspectives have little empirical substantiation casting doubt on the adequacy to explain the phenomenon (Eisenhardt, 1989). The types of research questions case study research is better suited to answering are “how”, “what”, and “why” (Yin, 2003).

Cases can focus on one or multiple units of analysis, can feature the qualitative and quantitative data and use a deductive or inductive theory generation approach (Cavaye, 1996). The approach highly versatile and can be adopted under both positivist and interpretivist epistemological positions. Information systems research features several examples of case study research (Orlikowski and Baroudi, 1991; Cavaye, 1996). The positivist stance in conducting case study research has been more prevalent in the information systems literature. However, the interpretivist position has been gaining traction within the information systems research community (Walsham, 1995; Tsang, 2014).

Novel theory is likely to emerge from case studies. The emerging theory link with the evidence from which it is constructed also improves its empirical validity (Eisenhardt, 1989). From a positivist perspective, case studies are often criticised for the impossibility to generate statistical generalisations. However, findings from case study research can claim theoretical generalisability (Cavaye, 1996).

Survey research can be an alternative to overcome the generalisation shortcomings of case study research. However, surveys are relatively inflexible to discoveries during the data collection process. Furthermore, the researcher would be required to have an idea of the answer before starting the research (Gable, 1994). Survey research also decontextualises the data, in order to claim statistical generalisability. The exploratory nature of this investigation combined with the uncertainty regarding the boundaries between the phenomenon and the context made a survey approach less appropriate for this research.

The literature on landside congestion at marine terminals seems to be underdeveloped with respects to the factors that generate congestion. The landside congestion management, transport and terminal management fields appear to segment the problem situation to the extent to which many results and findings become disjointed from the real-life situations they are inspired from. As this investigation explores factors conducive to the appearance of congestion and mitigation mechanisms, a case study approach was considered appropriate.

4.3.1.2 Multiple cases

Multiple case studies approach presents a series of relative advantages. Multiple cases can partially overcome the shortcomings of a single case with respect to its generalisability, the causal relations identified (Cavaye, 1996), and the possibility that findings result from case idiosyncrasies (Miles and Huberman, 1994). The data collected can be triangulated (Eisenhardt, 1989), not only from multiples sources within the case but also across cases. Emerging concepts from the data can be developed and subsequently compared in light of the different contexts the cases are set in (Cavaye, 1996). The potential inherent researcher bias be mitigated by the juxtaposition of evidence both supporting and conflicting existing beliefs and views (Eisenhardt, 1989). Multiple cases are conducive to cross-case comparisons and analyses. This process provides the opportunity to examine the case idiosyncrasies and ensure that the emerging findings are not a result of the specific case setting, thus enhancing their generalisability.

The number of case studies recommended is an ongoing debate in the research literature. Miles and Huberman (1994) suggest that the research questions and data collection process are likely to determine the number of case studies. Eisenhardt (1989) argue that between 4 and 10 cases can provide sufficient depth and complexity to generate a convincing, empirically grounded theory. It was important that the cases chosen would be representative of the Australian forest products exports. This investigation adopted a multiple case studies approach that included 3 case studies.

The case study selection approach can vary according to the philosophical position of the researcher. On the one hand, from a positivist perspective, case studies can be selected to replicate directly – similar results in a different setting - or theoretically – different results for predictable reasons replication (Yin, 2003). On the other hand, from an interpretivist perspective, researchers argue for theoretical sampling to explore a phenomenon of interest (Eisenhardt, 1989; Flyvbjerg, 2006). Case studies can be selected for maximum variation, extreme or deviant examples, paradigmatic or critical cases (Flyvbjerg, 2006). The case selection procedure is discussed in more detail in Section 4.4.1.

The unit of analysis for the case studies is an important consideration to ensure consistency of the approach and a relatively comparable data collection and analysis. One of the central arguments of this investigation was that the disparate literature perspectives as well as the disjointed decision making within the supply chain affecting other elements of the chain. Therefore, the unit of investigation of the case study was the forest products export supply chain, primarily focused on landside elements, which included either a bulk cargo marine terminal or an associated inland terminal.

In summary, a multiple case studies approach was considered the most appropriate research strategy for this investigation. This investigation included 3 case studies. Each case was centred on a forest products export supply chain, primarily focused on landside elements, which included either a bulk cargo marine terminal or an associated inland terminal. The next section discusses the three-stage participatory design approach applied in each case.

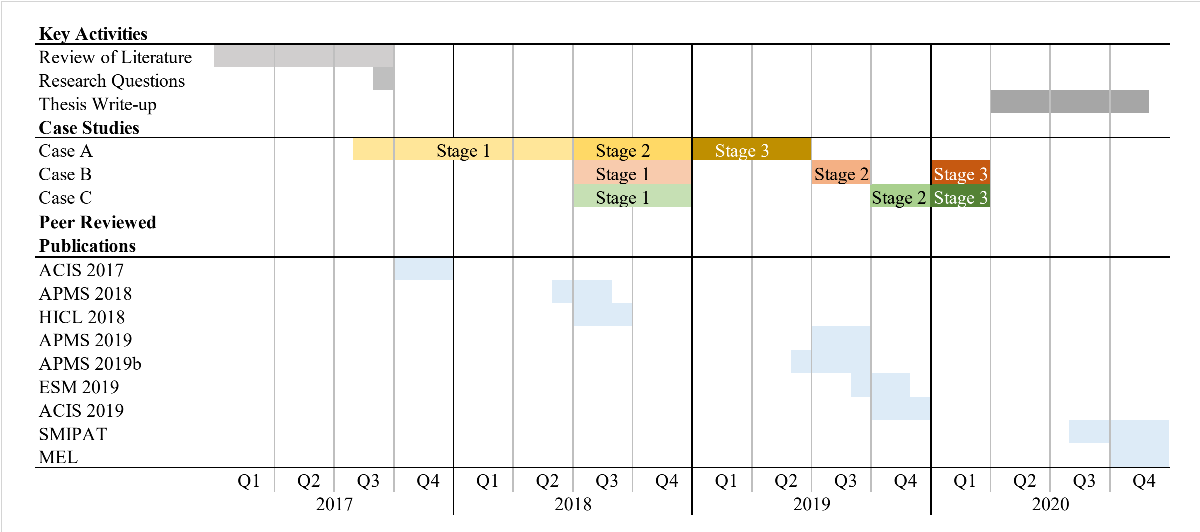
4.3.2 A Three-Stage Participatory Design Approach

A three-stage participatory design approach was adopted for each of the cases. The participatory design approach was considered most appropriate in this research because it is specifically tailored to cater for aligning potentially diverging perspectives across stakeholders. Furthermore, participatory design can facilitate the development of contextually relevant designs to issues. This section describes the three-stage participatory design approach adopted including the aims of individual stages.

Participatory design can facilitate mutual understanding, building of trust and compromise as well as conflict resolution and the emergence of situated designs through engagement through the use of a variety of methods. By exploring how "*professionals in their practice master their messiness and complexity*" (Bannon and Ehn, 2012) both the researcher and stakeholders can gain a better understanding of the system in which they operate. The bottom-up approach to design can also help highlight innovative practices in the context of resource scarcity (Bannon and Ehn, 2012). In technology implementations, a better understanding of the system can increase the likelihood that the emerging design includes useful features (Damodaran, 1996) when changes to the design are less costly and time consuming (Kujala, 2003). The stakeholders' involvement in the design can also increase the likelihood of user acceptance (Damodaran, 1996). The improved understanding and trust can also facilitate the emergence of innovative designs for work which are contextually dependent, negotiated and based on a holistic understanding of the system.

4.3.2.1 A Three-Stage Approach

The participatory design approach utilised both quantitative and qualitative methods and was divided into three stages: Stage 1: Exploration, Stage 2: Design Workshops and Stage 3: Evaluation.



ACIS = Australasian Conference on Information Systems; HICL = Hamburg International Conference of Logistics; APMS = Advances in Production Management Systems; ESM = European Simulation and Modelling Conference; SIMPAT = Journal of Simulation Modelling Theory and Practice; MEL = Maritime Economics and Logistics;

Figure 4 Research Timelines

Figure 4 illustrates the key activities in the research, the three case studies, the temporal progression of research stages for each case and the peer reviewed publications that were associated with this research. The research stages for each of the case studies were discussed.

Stage 1: Exploration aimed to provide a baseline understanding generated primarily from the analysis of qualitative data on the participants perceptions of congestion and factors contributing to it, as well as insights into congestion impacts and potential mitigation mechanisms. Qualitative data was collected which consisted of *observation* and *semi-structured interviews*. The qualitative data were analysed using *a coding process drawing on the principles of grounded theory*. Quantitative data collected during this stage. Quantitative data on truck processing times at terminals was collected by terminal systems using RFID readers or through on-board GPS units on trucks. The sequential qualitative-quantitative data collection approach was developed in a triangulation design. The dependency of quantitative knowing on qualitative knowing is explained by Campbell (1988): Numbers are representations of aspects of reality and meaningless unless the analyst understands the way in which the numbers map to aspects of reality (Campbell, 1988). The quantitative data were therefore primarily analysed following the completion of the qualitative data collection and analysis and was presented and discussed as the preamble for the workshops.

Stage 2: Design Workshops aimed to capture joint understanding of the participants' perceptions and facilitate the alignment of perspectives and the development of a common vocabulary amongst participants. The results of the quantitative data analysis were presented and discussed during the workshops as part of the development of a common vocabulary. Furthermore, the workshops included a design component in which participants, using the common vocabulary, could develop congestion mitigation approaches for their supply chains. The workshops followed a development design thinking, to inform further developments. The quantitative data collected in the previous stage were analysed using *simulation modelling* and *exploratory data analysis* techniques (including data visualisation, statistical summarisation and testing). The qualitative data collected during stage2: design workshops were analysed using *grounded theory coding principles*.

Stage 3: Evaluation aimed to explore the effectiveness of the participatory design process on the participants' understanding of congestion. The sequence of data collection and analysis techniques in this stage was modelled on a complementarity design. The effectiveness of the participatory design approach was assessed from qualitative data emerging during the workshops and the evaluation *semi-structured interviews*. It was unclear from the onset of the research whether the participatory design would be an effective approach in yielding designs and whether these designs would be implemented by the organisations in each case study. The evaluation therefore included a second component to understand the impact of the participatory design approach. The impact of the participatory design approach was evaluated using the qualitative data collected in the evaluation interviews and, where relevant and possible, using quantitative data.

In summary, a three-stage mixed method approach was adopted in this investigation. Qualitative and quantitative data collection and analysis techniques were used for data complementarity, development of instruments and analyses, and initiation.

The next section presents the rationale and choice of qualitative and quantitative data collection and analysis techniques used in this research.

4.3.3 Mixed-Methods

A mixed-method approach presented a series of advantages in the context of this research. The complexity, contextual dependency of the world means that a complete and definite account of a phenomenon is not possible, although some accounts may have more comprehensive views than others. Mixed methods allow for creating a fuller, richer account of the phenomenon (Cavaye, 1996; Glogowska, 2011), and the generation of a more integrated and comprehensive understanding of the topic (Halcomb and Hickman, 2015). The exploratory nature of the investigation meant that it was unclear from the onset what the key facets of the issue of congestion had most impact and conversely which mitigation approaches could be most effective. Therefore, a mixed-method approach was adopted in this research to attempt to capture a diverse set of aspects describing the phenomenon of interest.

The purpose of the mixed-method approach determines the sequence of the data collection and analysis. Greene, Carcelli and Graham, (1989) categorised mixed-method approaches in: complementary, development, initiation and triangulation designs. Different facets of a phenomena can be investigated through sequential use of two methods in a *complementary design*, to enhance or elaborate their individual results. The degree of dependency between the methods is increased in a *development design* where the results of one approach are used to sample, or inform the development of an instrument or analysis for the other method (Greene, Carcelli and Graham, 1989). *An initiation design* or "holistic triangulation" (Jick, 1979) is used when contradictions and paradoxes are identified or to purposefully look for such areas of non-convergence to initiate novel conclusions or further analysis (Rossman and Wilson, 1985). *A triangulation design* considers the inherent biases of qualitative and quantitative methods

(Halcomb and Hickman, 2015) and therefore warrants the independent implementation of methods to cross-check results. The categorisation of mixed-method sequences developed by (Greene, Carcelli and Graham, 1989) has been used to explain the rationale behind the sequencing of the qualitative and quantitative techniques in this research.

4.3.3.1 Qualitative Techniques

The rationale and types of qualitative techniques utilised in this research will be discussed. The qualitative data collection techniques used include: site visits and observations, semi-structured interviews and workshops.

4.3.3.1.1 Semi-Structured Interviews

Qualitative interviews are a frequently used data collection method in information systems research (Jones and Nandhakumar, 1997). Interviews can capture the diverse aspects of the social world from the perspective of those involved without the reliance on numbers (Horrocks and King, 2010). People's understanding of the world, their activities and their life can be revealed through interviews (Kvale, 1996). Particularly in case study research, interviews are considered one of the most important sources of information (Yin, 2003). These can often be combined with other qualitative data collection techniques such as observation and document review (Orlikowski and Baroudi, 1991).

Some of the characteristics of qualitative interviews are their flexibility and open-ended nature. The focus of interviews generally falls on people's experiences rather than beliefs and opinions and the relationship between the interviewee and interviewer is a crucial influencing factor for the approach (Horrocks and King, 2010). Furthermore, interviews allow the development of an in-depth understanding of organisations and social interactions as the researcher can examine not only what is explicitly stated but also what is not (Kendall and Kendall, 2010). These characteristics make interviews an appropriate technique in this research.

4.3.3.1.2 Site Visits and Observation

Site visits and observations allow the researcher to increase familiarity with the sites and the participants. Importantly, the researcher can increase understanding on the supply chains, terminal processes as well as observe congestion first-hand. Observing organisational settings and interactions between participants was useful in understanding every day behaviours and experiencing rather than solely relying on interview data (Pope, Van Royen and Baker, 2002).

4.3.3.1.3 Workshops

Workshops are a key component of participatory design (discussed in Section 3.4.2.2). Workshops were utilised in this research for several reasons:

- Congestion is conceptualised in this research as a 'wicked problem' which requires a holistic approach to better understand, identify causes and potential approaches to mitigate it. Individual engagement with stakeholders through qualitative techniques can yield valuable insights. However, the potential of participatory design to facilitate the emergence of innovative, contextually relevant designs based on mutual understanding was deemed worthwhile to explore. Importantly, as the designs are negotiated and agreed upon by stakeholders themselves, the likelihood of implementing designs can also be increased.

- The foundation of participatory design is rooted in socio-technical systems that conceptualise work systems as social and technical sub-systems and the interaction amongst them which require a balanced approach (Bannon and Ehn, 2012). The review of the research literature on landside congestion management revealed the tendency of researchers to focus on the technical system while paying less attention to the social system and the socio-technical interactions.
- Contemporary approaches to managing congestion tend to prematurely limit engagement for the development of a solution to contractual customers, leaving some of those primarily affected by change (e.g. transport companies) without a voice and a say in the process. Researchers investigating the effectiveness of implementations in real-life settings have reported the negative consequences of the lack of involvement of transporters in terms of the resulting system incompatibility with business requirements (Giuliano and O'Brien, 2007) misuse and abuse (Morais and Lord, 2006), and additional costs for transporters (Davies, 2009). Therefore, an approach that emphasises the inclusion of stakeholders affected by change was required.

Workshops were used to build upon insights gained from an individual level, include stakeholders in the design and decision-making process and facilitate mutual understanding and agreement on contextually grounded designs to mitigate truck congestion at bulk cargo marine terminals for forest products.

4.3.3.1.4 Grounded Theory Coding Principles for Theory Building

Grounded theory is a "*qualitative research method that uses a systematic set of procedures to develop an inductively derived theory about a phenomena*" (Strauss and Corbin, 1990). The grounded theory approach opposes the idea of "armchair theorising" (Corbin and Strauss, 2014) and is premised on an inductive theory building process as a result of successive data collection and analysis stages. A grounded theory approach can help create a holistic understanding of phenomena from the participants' points of view (Charmaz, 2006) and reveal insights on how individuals interact within a complex system (Randall and Mello, 2012). The grounded theory approach is explicitly opposed to the logico-deductive theory building and verification model (Ezzy, 2002) and opposed to methods where predefined categories are imposed on the data collected from field sites (Glaser, 1992). Consequently, themes and concepts are derived from the data.

Grounded theory is conceptualised as a journey of discovery (Strauss and Corbin, 1990) particularly well suited where formal theory and previous research are limited (Seidel and Urquhart, 2013). A grounded theory approach offers flexibility in terms of the use of existing theories and literature in guiding the data collection and analysis. Pre-existing theories can serve as sources of inspiration (Walsham, 1995) to guide the identification of research problems and foci (Ezzy, 2002). However, the pre-existing theories should not constrain the data that is noticed (Ezzy, 2002). Therefore, the researchers must remain cognisant that pre-existing concepts may not fit the data and in which case these concepts should be discarded.

Grounded theory has seen an increase in popularity both in the information systems field (Wiesche *et al.*, 2017) as well as in the supply chain and logistics fields (Mello and Flint, 2009; Randall and Mello, 2012). In information systems research, grounded theory has been used to generate rich descriptions on empirical observations through to generating novel theories (Wiesche *et al.*, 2017). Grounded theory provides a lens that acknowledges the social nature of supply chains with inter-organisational and cross-cultural interactions amongst participants (Isenberg, 2008; Randall and Mello, 2012) and allows the researcher to grapple with complex phenomena such as the exercise of power amongst firms (Mello and Flint, 2009). Therefore, elements of grounded theory were used in this research to assist with data reduction, conceptualisation and the development of theory.

4.3.3.2 Quantitative Techniques

The rationale and types of quantitative techniques utilised in this research will be discussed. The quantitative data collection techniques used include: simulation modelling and exploratory data analysis.

4.3.3.2.1 Simulation Modelling

The research employed a discrete event simulation model of the bulk cargo marine terminal. A review of the relevant literature on discrete event simulation modelling in landside congestion management was presented in Section 3.3.3.1. The choice for a discrete event simulation model was driven mainly by the research questions and objectives to explore congestion factors and mitigation approaches. Therefore, the modelling approach should fulfil two important criteria:

- Depict relatively accurately the terminal's operations while allow for the influence of stochastic components. The model would be presented to the case study participants and therefore had to represent as closely as possible the operational setup and product flows as closely as possible, including unlikely extreme events.
- Allow for the sensitivity analysis among multiple scenarios with similar inputs. Prior to the model's development, stakeholders were consulted to understand the potential options to mitigate congestion. One aspect that became apparent during these discussions was the multitude of perspectives the stakeholders had. Therefore, and approach that would provide the opportunity to compare the expected consequences of various landside congestion management techniques under similar conditions was required.

While analytical methods such as optimisation and queuing approaches are typically favoured in academia (Li *et al.*, 2019), for the purposes of this research, simulation modelling was found most versatile, useful, and appropriate.

4.3.3.2.2 Exploratory Data Analysis

Exploratory data analysis is an approach to investigate the quantitative data collected in order to answer the questions "*what's going on here?*" (Behrens, 1997) and is often associated with a "*detective work designed to reveal the structure or patterns in the data*" (Haig, 2005). The approach provides the flexibility to identify and investigate phenomena that emerge during empirical research (Jebb, Parrigon and Woo, 2017). Exploratory data analysis relief on a series of fundamental principles relating to the researchers' flexibility in mental attitude towards the data and the willingness to find both expected and unexpected phenomena in the data (Tukey, 1993).

Exploratory data analysis is particularly useful when there is limited theoretical background that can guide prediction or confirmatory data analysis (Behrens, 1997). The approach can assist the researcher in detecting new patterns and inspire the development of data-driven hypotheses (Jebb, Parrigon and Woo, 2017). The analysis approach can also support the generation of a rich description of the data even when theories exist (Behrens, 1997). Importantly, the exploratory data approach uses mathematics as an epistemic tool rather than as an answer to a given problem. The underlying idea being that this position can help minimise the type III error: "*precisely solving the wrong problem, when you should have been working on the right problem*"(Mitroff, Kilmann and Barabba, 1979; Barabba, 1991).

Visual representation and inspection of the data is a key feature of exploratory data analysis as it can help overcome distortions generated by maximising data (Behrens, 1997). Furthermore, visual representation can help identify patterns that may not otherwise be captured by statistical methods and facilitate the identification of novel research directions thus maximising the value of the data collected (Jebb, Parrigon and Woo, 2017). Plots for univariate data such as boxplots or histograms, or bivariate data such as scatter plots can assist in detecting trends in the data are examples of techniques to represent data.

This research used exploratory data analysis techniques in analysing quantitative data. These techniques included visual representation, statistical summarisation and statistical testing techniques. The use of exploratory data analysis techniques aimed to minimise the probability of prematurely narrowing down on a set of causal factors and avoid to "*solving the wrong problem*".

In summary, qualitative and quantitative data collection and analysis techniques were considered to capture a richer, fuller account of the phenomenon of landside congestion in each of the cases. The qualitative techniques consisted of semi-structured interviews, site visits, workshops and grounded-theory based coding. The quantitative techniques consisted of simulation modelling and exploratory data analysis tools (including visual representation, statistical summarisation and statistical testing techniques).

The next section provides the case study vignettes for the three cases included in this research.

4.4 Case Studies Vignettes

This section contains the description of the three case studies' field sites. Case study A is described first. Case studies B and C are described next.

4.4.1 Case Study A

Case study A was a bulk cargo marine terminal in Australia which served two forestry companies that exported wood chips to overseas pulp and paper manufacturers. The map of the supply chain in Case A was represented in Figure 5. The overlapping boxes suggest that there is more than one actor or organisation involved in the respective stage of the supply chain. The scope of the case (highlighted in the red rectangle in Figure 5) extended from the forest companies wood chip production operations to the terminal operations. The wood chip supply chain starts however in the forest where trees are harvested from plantations (Figure 6) and processed on site or in specialised mills in the vicinity of the marine terminal (Figure 7).

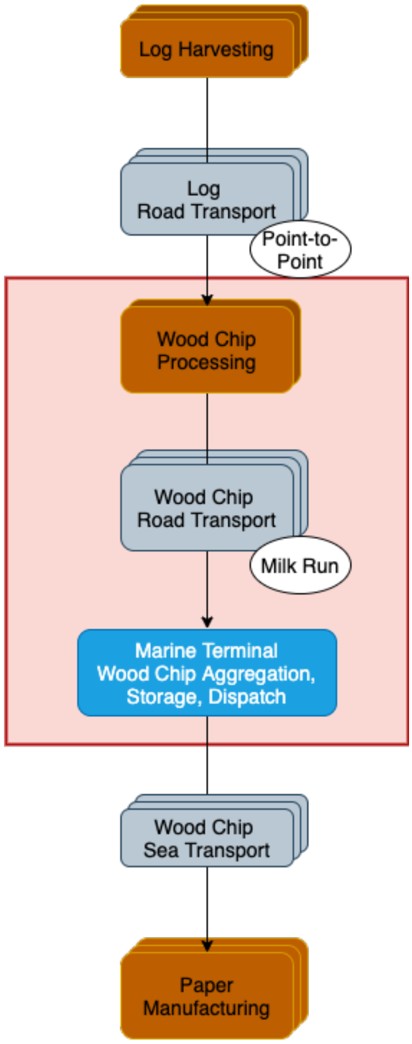


Figure 5 Case A - Supply Chain Map

Figure 6 Case A - Log Harvesting and Road-side Forwarding

Figure 7 Case A - Log Delivery and Unloading at Wood Chip Processing Mill

The two mills are located at approximately 90-minute round-trip and 40-minute round-trip respectively from the terminal and are serviced by two transport contractors. The two forestry companies deliver two different products that cannot be mixed at the terminal. Between the mills and the terminal, the two transporters run trucks in a cyclical delivery operation relatively independent from one another. Wood chips are stored at the marine terminal until vessels arrive and are loaded with the product (Figure 9) and (Figure 10). It can take between 1,200 and 1,600 deliveries to stock sufficient product to fill a vessel. Vessel scheduling is done by the forestry companies in isolation from one another.

Figure 8 Case A - Weighing and Queuing at the Marine Terminal

The unloading process at the terminal starts at the weigh-bridge where trucks are weighed, and their arrival time is recorded in the terminal database (Figure 7). Trucks operators then drive to the wharf where they wait for one of the two hydraulic ramps becomes available. The ramps tilt the trucks allowing the payload to slide into a common container located in the ground (Figure 8). If the product of the truck waiting to unload is different than the product being unloaded beforehand, trucks have to wait until the common container and the conveyor belt system are emptied before starting to unload. This is to prevent product mixing.

Figure 9 Case A - Truck Unloading at the Terminal

The container is emptied by a common conveyor system to a stockpile. Once the vehicles are emptied, the operators drive once more to the weigh-bridge where the empty weight of the truck and departure times are recorded. The difference between the two weights is used to calculate the throughput of the facility. The difference in departure and arrival times is used to calculate the truck turnaround time.

Figure 10 Case A - Wood Chip Storage at Marine Terminal

Figure 11 Case A - Terminal Layout and Vessel Loading

Historically, the entire supply chain from forest to the terminal operations was owned and operated by a single enterprise. Following a severe market downturn partly due to the global financial crisis and the collapse of the managed investment schemes (see Section 2.3.1), the supply chain became more fragmented, with multiple forestry companies, transport contractors and an independent terminal operator involved. In recent years, the facility's throughput had increased steadily. The constant increase in throughput was also associated with an increase in truck turnaround times leading to frustration and tensions between forestry companies, transporters and the terminal operator.

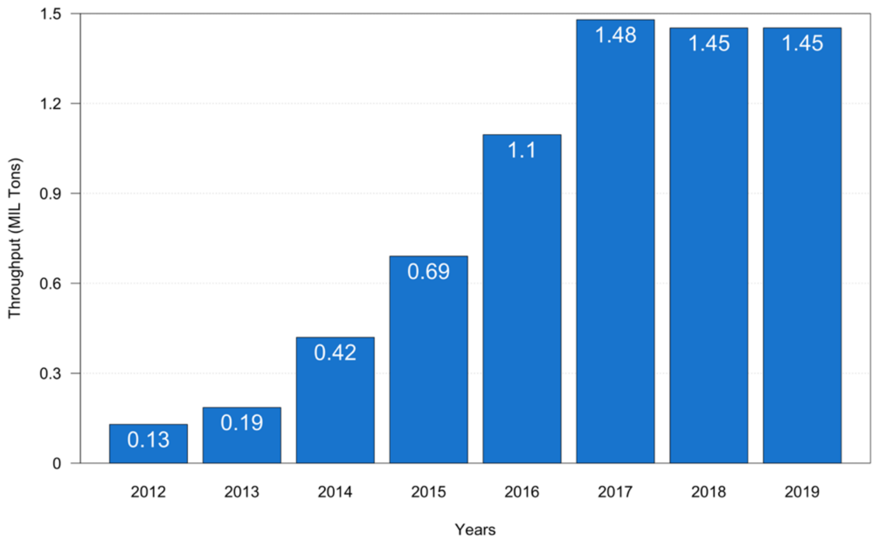


Figure 12 Case A - Terminal Yearly Throughput from 2012 to 2019

A truck can be unloaded without interruptions in 10-12 minutes. At the start of the research project, the average truck turnaround time was 22-24 minutes. Approximately 60% of trucks were unloaded in less than the average time, and 35% of trucks were unloaded in less than an hour. The remainder could take up to 150 minutes to unload. Given the relatively short driving distances between the mills and the terminal, the variations in turnaround times could impact the number of deliveries achievable in one shift of an operator, therefore reducing both labour and equipment productivity. Specifically, turnaround times over 25-minutes would reduce the number of daily deliveries for the trucks delivering in the 40-minute and 90-minute cycle. Congestion could also be compounded by adverse weather which could suspend truck delivery operations, leading to queues once the terminal would reopen. Given the economic impact of congestion there was significant interest in understanding the available alternatives to mitigate this challenge. The researcher together with the terminal operator and forestry companies therefore initiated the project to better understand the conducive factors to congestion as potential mitigation approaches.

The next section presents the vignettes for the other two case studies, B and C.

4.4.2 Other Case Studies: Case Study B and Case Study C

This section presents the vignettes first for Case study B and second for Case study C

4.4.2.1 Case Study B

The filed site for Case study B was a bulk cargo marine terminal in Australia which served two main customers, forestry companies, that export wood chips to overseas pulp and paper manufacturers. One forestry company manages a large proportion of chipping and haulage contractors and delivers wood to the terminal based on a wood supply agreement. The other forestry company also has a controlling stake in the terminal operator. The map of the supply chain in Case B was represented in Figure 13. The overlapping boxes suggest that there is more than one actor or organisation involved in the respective stage of the supply chain. The scope of the case (highlighted in the red rectangle in Figure 13) extends from the harvesting to the terminal.

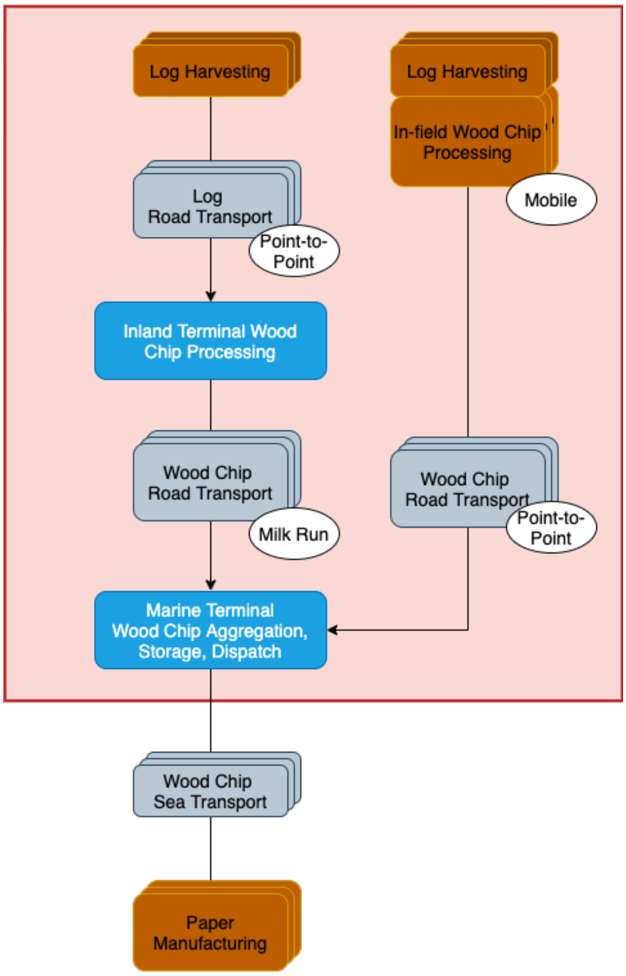


Figure 13 Case B - Supply Chain Map

Figure 14 Case B - Road-side Log Loading on Truck

The terminal is divided into two main components, the quay side located in the port precinct and the inland side located approximately 30 kilometres away from the port. The reason for this separation is that the inland side also acts as a mill which receives logs and processes them into wood chips.

Figure 15 Case B - Log Truck Weighing

Upon arrival at the inland side, the log trucks are first weighed on the weigh-bridge recording their time of arrival and full weight (Figure 15). Then the trucks are directed to one of three unloading booths. If no unloading booth is available, trucks queue on an internal road. Once the truck is parked at a booth, the truck operator unstraps the logs in the trailers and retreats in the booth. The trailers are unloaded by a grapple loader that picks up the logs in each trailer bay (this unloading process is similar to the one depicted in (Figure 7). The grapple loader can then lay the logs in the log yard in piles or can feed them directly to a woodchipper. The woodchipper loading belt can only be fed with a limited number of logs at one time. Thus, if logs are still on the loading belt, the grapple loader has to wait prior to adding more logs.

Figure 16 Case B - Wood Chip Vessel Loading

The quay side of the terminal receives deliveries of in-field produced wood chips 24 hours per day from two chipping contractors. The inland side of the terminal and receives deliveries of logs from 6 AM to 10 PM from seven harvesting contractors. Logs are processed into wood chips in the inland side of the terminal and transferred quay side using high-capacity A-double trucks that run 24 hours per day between the two sites. The majority of the wood chips are stored on the quay side of the terminal and subsequently loaded on vessels belonging to international pulp and paper manufacturers (see Figure 16). The in-field and inland transfer trucks utilise different unloading ramps at the quay side terminal. Given the limited overlap, congestion rarely ensues at the quay side of the terminal. Congestion does however frequently occur at the inland side of the terminal. Therefore, the case study is primarily centred on the inland side rather than quay side of the terminal.

Once the log truck trailers are empty, the truck operator drives once more over the weigh-bridge. This records the empty weight and the departure time of the truck. The weigh-bridge system reconciles the arrival and departure recording and stores the information into an SQL database. The difference between the full and empty weight determines the weight of the product delivered. The difference between the departure and arrival time determines the truck turnaround time. The data collected by the weigh-bridge system is insufficient to determine the waiting or unloading time duration.

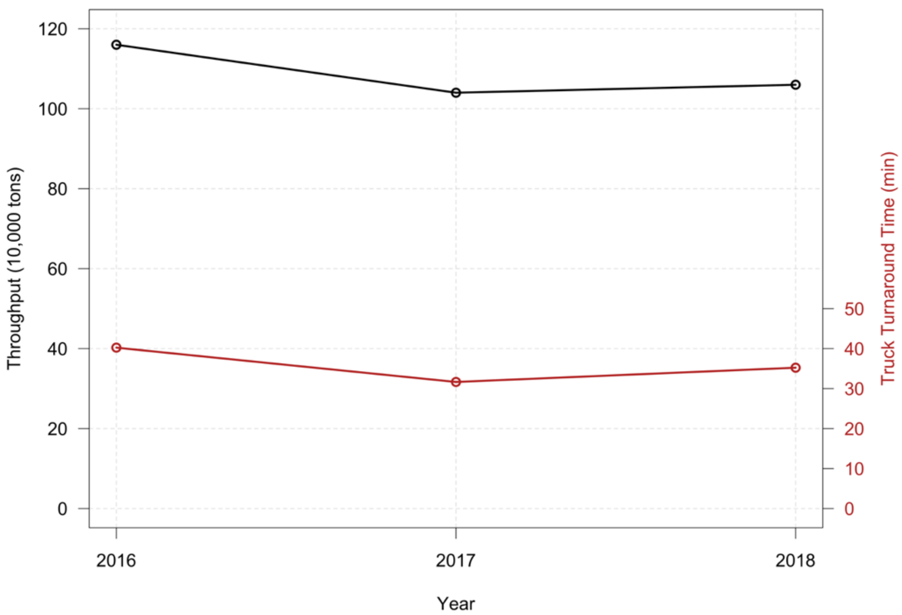


Figure 17 Case B - Yearly Throughput and Average Truck Turnaround Times

(*2018 figure is based on the researcher's extrapolation of actual throughput from January to July 2018)

The throughput of the inland terminal had remained relatively constant in the 2.5 years prior to the start of the study and was expected to continue on a stable trajectory. However, the terminal operator, harvesting and transport operator reported significant congestion challenges and trucks queuing for long periods of time. Much of the congestion occurred during the morning and related to trucks arriving prior to the inland terminal opening time. However, data on log truck turnaround times prior to the terminal's opening time was not accurately reported due to contractual requirements. Therefore, the extent of congestion remained unclear. The reasons behind trucks arriving prior to the terminal's opening time, an apparently irrational behaviour, were also not immediately obvious. The researcher initiated a project together with the terminal operator to better understand the factors conducive to congestion and also potential approaches to mitigate congestion.

4.4.2.2 Case Study C

The field site for this case study was a bulk cargo marine terminal on the Australian mainland. The map of the supply chain in Case C was represented in Figure 18. The overlapping boxes suggest that there is more than one actor or organisation involved in the respective stage of the supply chain. The terminal was used for the export of wood chips and is operated by an organisation which also managed harvesting operations as well as wood chip marketing to international customers. The terminal served the owner organisation and another forestry company. The wood chip supply chain in this case starts in the forest harvesting areas where the trees are harvested and directly processed into wood chips which are sprayed in truck trailers. The trucks then deliver the wood chips to the terminal. At the terminal, the wood chips are stored in expectation of specialised vessels. The scope of the case (highlighted in the red rectangle in Figure 18) extends from the harvesting to the terminal.

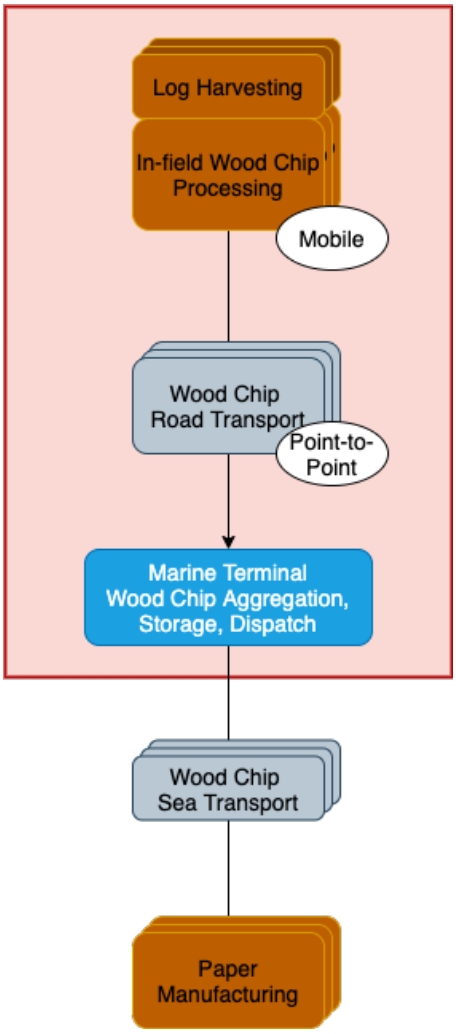


Figure 18 Case C - Supply Chain Map

The two organisations using the terminal employ up to seven chipping contractors who utilise their own mobile specialised equipment to harvest and process timber into wood chips. The chipping contractors are also responsible for delivering the wood chips from the *in-field* processing site to the terminal (Figure 19).

Figure 19 Case C - In-field Wood Chip Processing

Some chipping contractors manage transportation with their own trucks. Other contractors use external transport operators for this task. Most transporters utilise high-capacity *B-double* trucks with a carrying capacity between 40 and 50 tons (see Section 2.2.3 for details on common truck configurations). The forest harvesting sites are located at distances varying from 30 to 250 kilometres from the terminal. A quarter of trucks travel from a harvesting sites less than 100 kilometres from the terminal. Approximately half travel between 100 and 150 kilometres and the rest travel more than 150 kilometres.

Figure 20 Case C - Trucks Queuing in Terminal Staging Area

At the terminal, the trucks are first weighed on the weigh-bridge recording their time of arrival and full weight. Then, trucks drive to a staging area where they wait for one of the three unloading ramps to become available (Figure 20). Once an unloading ramp is available, operators drive on the ramp and begin unloading (Figure 21). The truck is raised and tilted such that the wood chips slide out of the trailers into a common bin. All three unloading ramps use the same conveyor belt system.

Figure 21 Case C - Truck Unloading at Terminal

The conveyor runs past a magnet that can pick up metal contaminants and into a screening system. The screening system redirects wood chips that are beyond a size threshold into a re-chipper. The capacity of the re-chipper is however limited. Thus, if a significant amount of oversized wood chips is delivered, the conveyor belt system slows down until the re-chipping is completed. The conveyor belt slow down also delays the unloading process. Figure 22 shows a re-chipper used prior to vessel loading, similar to that used to process wood chips from trucks.

Figure 22 Case C - Re-Chipper Station

Once re-chipped, another conveyor belt system carries the chips onto a stockpile. The stockpile can store sufficient product to fill 3-4 ships depending on their size (Figure 23). Once trucks are empty, the unloading ramps is lowered, and the operator drives off the ramp.

Figure 23 Case C - Wood Chip Vessel Loading Using Mobile Conveyor Systems

The truck are weighed once more recording its empty weight and departure time. The weigh-bridge system reconciles the arrival and departure recording and stores the information into an SQL database. The difference between the full and empty weight determines the weight of the product delivered. The difference between the departure and arrival time determines the truck turnaround time. The data collected by the weigh-bridge system is insufficient to determine the waiting or unloading time duration. The turnaround time indicators are reported and generally used in discussions with chipping and transport contractors.

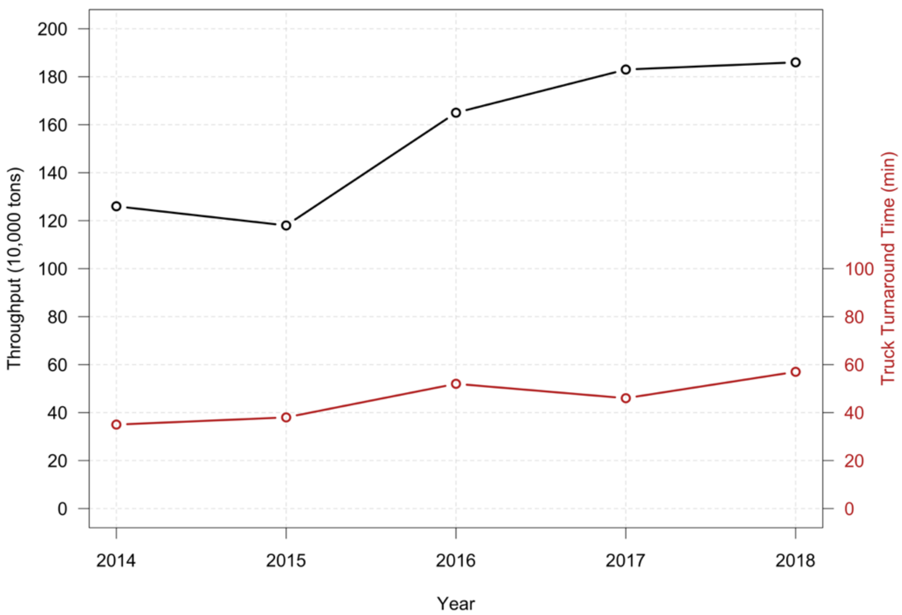


Figure 24 Case C - Yearly Throughput and Average Truck Turnaround Times
(*2018 figure is based on the researcher's extrapolation of actual throughput from January to July 2018)

The throughput of the facility had been steadily increasing following a decrease in volumes partially due to the global financial crisis. Throughput had stabilised around the 1.8 million tons from 2017. However, from 2017, truck turnaround times had been deteriorating and reached an average of 57 minutes in the first half of 2018. The evolution of the facility's throughout and truck turnaround time is illustrated in Figure 24. Truck turnaround times reached more than 90 or 120 minutes leading to frustration but also additional expenses from the transporters' side. Contaminated and oversized chip deliveries contributed to the increased turnaround times. However, there was no clear understanding of the extent to which the various issues affected truck turnaround times. The terminal was also space constrained which limited infrastructure investment options to alleviate congestion. Terminal operator was interested to explore alternatives to manage congestion. The researcher initiated the project, together with the terminal operator and logistics companies, to better understand the conducive factors to congestion as well as potential mitigation approaches.

The next section presents the research design, and specifically the data collection procedures utilised for the case study selection and for the three stages of the approach.

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4.5 Research Design: Data Collection Procedures

The research procedures utilised by the researcher are described in this section. Data collection and analysis was undertaken by the researcher in multiple stages of the research. Each phase and data collection wave were analysed and informed further data collection from the same case as well as for the other field sites.

4.5.1 Case Study Selection

Three case study field sites, representing three forest products exports terminals or offshore processing facilities closely related to the terminals, were selected for this research:

- ***Case Study A*** centered on the Burnie Chip Export Terminal (BCET), a bulk cargo marine terminal exporting hardwood chips, in Burnie, Tasmania and operated by the Tasmanian Ports Corporation.
- ***Case Study B*** focused on the Portland Chip Terminal (PCT), a bulk cargo marine terminal exporting hardwood chips, located in Portland, Victoria and operated by Australian Bluegum Plantations
- ***Case Study C*** centered on the Portland Grain Corp Terminal and its hinterland component, the Myamyn mill in Victoria operated by South-West Fibre. The hinterland terminal processes hardwood logs into wood chips and transfers the wood chips to the Portland Grain Corp Terminal located in close proximity to PCT

The data collection and analysis for Case A took place between August 2017 and July 2019. Cases B and C had similar commencement times with data collection and analysis starting in June 2018 and lasting until March 2020. The research data collection timeline is summarised in Table 7.

Table 7 Case Study Data Collection Timeline

Data Collection	Case Study A	Case Study B	Case Study C
Stage 1: Exploration	**Q3 2017 – Q2 2018**	**Q2-Q3 2018**	**Q2-Q3 2018**
Observation and Site Visits	5 visits	4 visits	4 visits
Semi-Structured Interviews	12 (7 tape-recorded)	4 (2 tape-recorded)	9 (2 tape-recorded)
Weigh-bridge Data	9 months (40,000 entries)	2.5 years (62,000 entries)	4.5 years (170,000 entries)
GPS Data	3 months (16,500 entries)	N/A	N/A
Interview Respondents*	*Alex (TO)*	Arthur (TO/WP)	*Anthony (TO/FC)*
	Bobby (H)	Beatrice (TO/WP)	*Brian (TO/FC)*
	Charles (FC)	*Carter (H&H)*	Christine (C&H)
	Danny (FC)	*Damien (H&H)*	David (C&H)
	Elliott (FC)		Eric (C&H)
	Frank (TO)		*Fred (C&H)*
	Garry (WP)		Gabriel (C&H)
			Henry (C&H)
Stage 2: Design Workshops	**Q3-Q4 2018**	**Q3 2019**	**Q4 2019**
Workshops	2 (10 & 3 participants*)	1 (9 participants)	1 (7 participants)
Workshop Participants	*Alex*	Arthur	*Anthony*
	Bobby	Beatrice	*Brian*
	*Charles**	*Carter*	*Fred*
	Danny	*Damien*	Kevin (H)
	*Elliott**	Edward (C&H)	James (C&H)
	*Frank**	David (C&H)	Laurence (FC)
	Garry	Gavin (WP)	Michael (C&H)
	John (FC)	Hector (C&H)	
	Harry (FC)	Flynn (FC)	
	Ian (FC)		
Stage 3: Evaluation	**Q1-Q2 2019**	**Q1 2020**	**Q1 2020**
Weigh-bridge Data	3.5 months (13,000 entries)	N/A	N/A
Semi-Structured Interviews	5	2	4
Interview Respondents	*Alex*	*Carter*	*Anthony*
	Bobby	*Damien*	*Brian*
	Charles		*Fred*
	Danny		James
	Elliott		
	Frank		

The names of the respondents have been changed to preserve their anonymity.
The participants in all three stages, exploration, design workshops and evaluation are highlighted in italics
TO = terminal operator; FC = forestry company; WP = wood-chip processor; H = log/wood-chip haulage operator; H&H = log harvest & haulage contractor; C&H = chipping & haulage contractor

Case A was the first selected for the investigation in Q3 2017. The selection of this case was based on reports from staff and supply chain stakeholders of significant landside congestion and their availability to participate in the research project. The selection of Cases B and C was based on theoretical sampling consideration (Corbin and Strauss, 2014), as well as purposive sampling (Lincoln and Guba, 1985). In terms of purposive sampling, a series of decisions were made to limit the potential field sites under consideration:

- The terminals and facilities considered exported or processed hardwood logs or wood chips and transported the products in bulk form (as opposed to containers). Focus on a single commodity is desirable in this as it limits the number of intersecting supply chains and reduces the number of potential environmental factors affecting the supply chains. Bulk terminals are, in general, focused on a single commodity which may limits the impact other port users, either on the maritime or land side, have on the terminal's operations.
- Given the limited timeframe of the research, a selection criterion for the terminals or facilities considered was to face significant levels of recorded or perceived truck congestion. The perception of truck congestion was primarily assessed by the terminal operator's staff.
- The availability of terminal operators' staff to engage in a research project was also an important consideration. While the issue of truck congestion was identified in multiple locations in Australia, some terminal operators were not interested, or had no availability to collaborate with the research team.

The additional field sites were selected as a result of insights gained in Stage 1: Exploration of Case A. Specifically, the two additional cases were selected to expand the breadth of the supply chain under study, to study variations in power and contractual relations, and to explore additional perceptions on congestion and mitigation techniques.

- **Supply chain breadth.** The supply chain stages to which the researcher had access to in Case A spanned from the wood chip production in the two mills up to the delivery of products at the terminal. Given the extensive research literature on forest logistics optimisation, it was likely that the complexity of harvesting operations contributed to the generation of congestion. The supply chain in Cases B and C included forest harvesting and processing operations. It was not possible to include the pulp and paper manufacturer side of the supply chain (i.e. the final customers for wood chip products) including the vessel selection and scheduling in any of the three case studies.
- **Power and contractual relations.** The terminal in Case A was owned and operated by a government business enterprise (GBE), a relatively uncommon situation in bulk cargo supply chains, where either the resource owner or a third party operates the terminal. In Case B, the terminal is integrated into the organisation of a forest owner and manager. The companies performing the harvesting and processing of the forest resource are subcontracted by the forest owner organisation. In Case C, the company controlling the off-shore facility also manages a forest estate but is also contracted to receive deliveries and process products belonging to another company, effectively coming close to replicating the situation in container shipping where the terminal operator and transporters delivering at the terminal have no contractual relation.
- **Congestion perception differences.** Discussions with stakeholders along the supply chain in Case A revealed different perceptions on where congestion was, its extent

and the mitigation approaches that would be most effective. The researcher suspected that the limited perspectives of stakeholders in Case A were not unique to the case. Therefore, Case B and Charlie were initiated in an attempt to replicate this result.

In summary, three case study field sites were selected for this research, each centred on a bulk cargo export marine terminal and their associated supply chains, focusing primarily on the landside elements.

4.5.1.1 Gaining Access

From the onset, it was recognised that organisations were less likely to allocate resources to a research project if there is little or no perceived benefit in engaging in the research. Early discussions with terminal or facility managers revealed that the supply chains were experiencing truck congestion. Where there was interest in exploring congestion, the approach adopted for gaining access to field sites, participants and data was to present a brief report detailing the researcher's insights and understanding during the engagement with the case participants. The researcher presented a simplified version of the research plan in a project proposal to the terminal operator with outputs tailored to the issues the managers reported. The project proposals were structured around three key objectives:

1. A comprehensive and detailed mapping of the product delivery, terminal unloading process and upstream supply chain product and information flows.
2. Contractor engagement to ensure external factors and requirements are captured and, awareness is raised regarding the action undertaken to address the congestion issue.
3. A set of recommendations on the short term (operational and tactical) and on the long-term (strategic) pathways that can be pursued to address existing challenges including enhanced use of digital technologies.

The three terminal operators that agreed to proceed with the project proposals became the research field sites. The terminal operators' senior managers were the principal informants. The principal informants facilitated access to quantitative data and to other potential participants (contractor and customer representatives). Two of the three terminal operators also allocated a modicum budget to support the researcher's travel costs. This collaboration arrangement allowed the researcher to become a 'participant observer' (Walsham, 1995).

4.5.1.2 Researcher Involvement

The researcher acknowledges that there are advantages and disadvantages to the researcher's close participation in the investigation. The main advantage of the insider role of the researcher was becoming a temporary member of the organisation for short periods of time. The researcher was granted significant and seemingly unrestricted access to the data the terminal operators collected but also could partake in the daily experience of the organisation's staff. The presence of the researcher on site created the additional possibilities for impromptu data collection through '*watercooler conversations'* with the staff.

There were however a number of disadvantages associated with this approach. From a data collection perspective, in discussions with the terminals' users the researcher recognises that being introduced as conducting a study with the terminal operator can instil the perception that the researcher is representing the operator. As a result, that the users' accounts of their experience with respect to congestion can be influenced by commercial negotiations and power relations with the terminal operator. The participants may have also been guarded to share certain information if they perceived it could be used against them. From a bias and role perspective, the personal involvement of the researcher can increase the self-reporting dangers of over-modesty and self-aggrandisement (Walsham, 1995). Issues surrounding confidentiality can also arise given the limited number of stakeholders involved. The researcher therefore implemented a series of measures to minimise the impact of these disadvantages.

The measures introduced to minimise the consequences of researcher involvement were: engage participants in the research and with one another, limit discussions on confidential matters and the use of a socio-technical analytic lens.

- A practical reason that motivated the use of participatory design was to provide some form of value to terminal users for providing input in the projects and research. Therefore, issues raised by the users could also be raised during workshops, acknowledged and disputed by other participants. The decision to share part of the project reports' findings by the terminals' operators appeared to stimulate the engagement of their users.
- Discussions on confidential matters were limited in two ways: first, the reports contained no direct quotes or references to the participants that issues those statements and were framed in general terms; second, discussions on any financial matters were avoided. The contractual provisions between stakeholders were discussed when needed without references to monetary values. The researcher observed that financial matters appeared to be the most sensitive issues for stakeholders and therefore avoided the topic. Confidentiality agreements between the university and the terminal operators were signed in all three cases. In one of the cases, an additional layer of assurance was requested, the terminal users were also part of a multi-party confidentiality agreement.
- Finally, the analytic lens used by the researcher to interpret and analyse the data was that of socio-technical systems where the outcome of the system rather than individual parts and the interactions between the system's components, social, physical and informational, were of primary interest.

In summary, the researcher gained access to the field sites by involving participants in the research through projects that attempted to provide some benefit to the participating organisations in terms of insights on congestion.

The next section presents the data collection procedures utilised during Stage 1: Exploration.

4.5.2 Stage 1: Exploration Data Collection

During Stage 1: Exploration qualitative data were collected through site visits, observations and semi-structured interviews. Quantitative data were also collected from weighbridge and truck geo-tracking software. The qualitative data analysis techniques will be discussed in Section 4.6.1.1. The quantitative data analysis techniques will be discussed in Sections 4.6.2.1 and 4.6.2.2.

4.5.2.1 Site Visits and Observation

Site visits were undertaken to improve understanding of as much of the forest products supply chain as possible and are summarised in Table 8. The majority of visits covered landside operations.

Table 8 Site Visits Performed During the Primary Investigation

Date	Location	Site Visited	Field Site
Aug-17	TAS, AU	Road Transporter Depot	*Case A*
Aug-17	TAS, AU	Processing Facility - Wood Chip Mill	*Case A*
Oct-17	TAS, AU	HW Harvesting Operation	*Case A*
Jan-18	TAS, AU	Wood Chip Export Terminal	*Case A*
Oct-18	TAS, AU	Wood Chip Export Terminal	*Case A*
Aug-18	VIC, AU	HW Harvesting Operation	*Case B*
Aug-18	VIC, AU	In-field Chip Processing	*Case B*
Aug-18	VIC, AU	Wood Chip Export Terminal	*Case B*
Dec-18	VIC, AU	Wood Chip Export Terminal	*Case B*
Nov-18	VIC, AU	Wood Chip Export Terminal	*Case C*
Nov-18	VIC, AU	Processing Facility - HW Sawmill	*Case C*
Nov-18	VIC, AU	Wood Chip Vessel Loading	*Case C*
Nov-18	VIC, AU	Road Transporter Depot	*Case C*

[a] HW = hardwood; [b] SW = softwood

In each of the case studies, the site visits helped with understanding the reality experienced by stakeholders and their actions in their usual environments.

4.5.2.2 Quantitative Data

Quantitative data was collected from each of the tree case studies primarily from weigh-bridge systems. Global positioning systems (GPS) data generated from units mounted on trucks were also collected in Case A, where one organisation was willing to provide access to the researcher. The quantitative data collection schedule, data types and data coverage are detailed in Table 9.

Weigh-bridge data typically contained details on date and time of the truck arrival and departure, truck identification and weight (gross, net, and tare), and duration of visit at the facility. In cases B and C, where trucks generally arrived directly from forest operations, the operation code was also included. The operation code provided information on the distance between the harvesting operations and the facility

One transporter in Case A agreed to provide the researcher with access to the GPS software provider portal where truck telemetry data could be downloaded. The transporter had already set-up geo-fences around the areas of interest at the terminal (weigh-bridge and unloading ramp) and collected approximately 3 months of data. These data were downloaded in a .csv file and further processed using Microsoft Excel and R statistical software.

Table 9 Quantitative Data Collection Schedule, Data Type and Coverage

Field Site	Collection Time	Type of Data	Data Coverage
Case A	September 2017	GPS geo-fence data - Visit duration in geo-fence/truck	1st June 2017 – 30th September 2017
	April 2018	Weigh-bridge data - Individual truck arrivals	1st January 2017 – 30th September 2017
	February 2019	Weigh-bridge data - Individual truck arrivals	28th January 2019 – 22nd February 2019
Case B	September 2018	Weigh-bridge data - Individual truck arrivals	1st January 2014 – 31st July 2018
Case C	August 2018	Weigh-bridge data - Individual truck arrivals	1st January 2016 – 31st July 2018

Additional details end excerpts of the quantitative data collected can be found in Appendix C.

4.5.2.3 Semi Structured Interviews

Semi-structured interviews were used as a primary data collection technique in Stage 1: Exploration as well as Stage 3: Evaluation. Participants in commercial and operations roles from the three case studies were invited to participate. In total, 25 interviews were conducted in Stage 1: Exploration. Respondents from Stage 1: Exploration were invited to participate in Stage 2: Design Workshops and Stage 3: Evaluation

4.5.2.3.1 Participant selection

Key personnel within the case studies, internal to the organisation or external, were primarily identified using the key informants, who also provided contact details for the participants. The participants were contacted by the researcher and asked whether they are interested in participating in the interviews. If they agreed, a suitable time and date were set for a meeting.

Participants were purposively and dimensionally sampled to find those that are knowledgeable and reliable in reporting usual events in the supply chain (Miles and Huberman, 1994). Participants' roles were the primary dimension on which the selection was conducted. Commercial roles such as business development, and operations roles such as operations, port or logistics management as well as port supervisor or transport coordinator were of interest. In some of the smaller companies in the supply chains with few employees, multiple roles were often performed by one person. Commercially oriented roles of interest because of their involvement in contract negotiations and other financial matters. Consequently, the researcher expected that insights regarding the influence of financial incentives and considerations on congestion mitigation approaches as well as supply chain behaviours could be generated from participants in commercial roles. Insights regarding '*naturally occurring ordinary events*' (Miles and Huberman, 1994), operations, challenges and behaviours were likely to be generated from participants in more operationally oriented roles.

4.5.2.3.2 Building Trust and Rapport

Once contact was established with participants it was important to build trust and rapport. The researcher had been exposed to the industry-specific vocabulary and became more acquainted with the specificities of timber products supply chains. On several occasions, the researcher mentioned having previous work experience in transportation and logistics. These previous experiences appeared to facilitate the rapport development with participants.

The researcher discussed the research and its aims with participants and provided information sheets (Appendix A) and interview consent forms (Appendix B) detailing how the data obtain are used, the right of participants to consult records and withdraw from the study without providing explanations. To support trust and rapport building, the first interaction with the interviewees was not tape recorded, however, the researcher took notes during the discussion. The primary concern with regards to tape recording was that the interviewees may be less open and forthcoming with regards to certain issues (Horrocks and King, 2010). In the cases where the researcher met the interviewees more than once, the interviewees were requested to indicate whether they allow the interview to be tape recorded. A total of 11 interviews were tape recorded. The names of all participants have been changed to protect their anonymity.

4.5.2.3.3 Interview Design

A semi-structured interview schedule was used in both stages of semi-structured interviews, primarily due to its flexibility. Open-ended questions allow for a relatively unimpeded exploration of experiences and attitudes (Pope, Van Royen and Baker, 2002) as well as allowing the researcher to adapt to the field situation, explore in additional depth a particular area of interest or order questions differently. A primary disadvantage of this approach is the possibility that participants can fabricate, exaggerate or distort information (Pace, 2004) either willingly or due to recognised cognitive biases such as the "*recency effect*" (Kahneman, 2011) that can play a role in the recollection process. Distortions, exaggerations or recent events can also be useful indicators of participants' perceptions regarding the issue discussed. Therefore, while the researcher triangulated interview data with other qualitative and quantitative data sources, distortions during interviews were noted as relevant points for the analysis process.

The semi-structured interviews, part of Stage 1: Exploration, were conducted over the phone at a previously agreed time or face-to-face in familiar environments for the respondents', either their (private) offices or in conference rooms located on their organisations' premises. 25 interviews were conducted (12 for Case A, 4 for Case B and 9 for Case C) and ranged from 30 to 90 minutes in length. 11 interviews took place face-to-face and were tape-recorded, 12 took place face-to-face and were not tape-recorded and 2 took place over the phone and were not tape recorded. The question frame used during the interviews was divided in 5 categories of questions: Background, responsibilities, information and technology use, congestion challenges and consequences and management approaches:

- **Background/Demographic** questions were aimed to understand the respondent's experience in the industry and the types of roles the respondent had in the past. The researcher observed during initial interviews that participants were more tense after the interview recording was started. The discussion about the respondent's history and work experiences facilitated easing this tension.
- **Responsibilities** questions aimed to provide detail on what the respondents' incentives and responsibilities are with respect to the general operations of the company. Initial questions in this category revolved around the general operations of

the company, whilst subsequent questions narrowed-down on the specific tasks of the respondent.

- **Information systems use** questions aimed to understand how information is being used and shared and which sort of tools facilitate the collection, storage, dissemination and use of data and information. Generally, the initial question used was regarding their role, responsibilities and daily routine. The researcher noticed that questions regarding information used were typically answered by discussing the technology and data available rather than their actual use. Following initial responses, the researcher ensured to ask what data was used for in daily or routine operations.
- **Congestion challenges** questions aim to explore the respondents' perceptions of congestion, its gravity, causes and consequences. The respondents were encouraged to describe their experiences and behaviours with respect to truck congestion and provide examples of situations in which congestion is experienced.
- **Landside congestion management approaches** questions aimed to highlight the types of mechanisms the respondents consider useful in addressing landside congestion. The researcher encouraged the respondents to discuss any type of approach, irrespective of perceived feasibility.

Background and responsibilities questions were primarily used in the tape-recorded interviews to start the conversation with respondents on familiar grounds and gain some understanding of the respondents' context. The interviews that were not recorded were generally shorter and focused more on congestion, management approaches and the use of information systems.

In summary, the data collected in Stage 1: Exploration aimed to provide the input for generating a baseline understanding of the participants perceptions of congestion and factors contributing to it, as well as insights into congestion impacts and potential mitigation mechanisms.

The next section presents the data collection procedures utilised in Stage 2: Design Workshops.

4.5.3 Stage 2: Design Workshops Data Collection

At least one workshop was conducted in each of three case studies. Qualitative data resulting from the participants' interactions were collected during the workshops. The qualitative data analysis techniques employed on the workshops data will be discussed in Section 4.6.2.3.

Stage 2: Design Workshops were conducted once Stage 1: Exploration was completed and a brief report summarising Stage 1: Exploration results was presented to the participants. The workshops aimed to include the relevant terminal operators' staff as well as external staff involved or affected by land transport operations. The intention of the researcher to conduct participatory design sessions with supply chain members was made explicit from the project proposal stage. However, the degree of willingness to engage in the participatory design process with the external supply chain stakeholders varied across the three cases. The workshops were hosted by the terminal operators on their premises and included between 10 and 12 participants including the researcher and research project coordinators. Each workshop lasted between 3 and 4 hours. The workshops were audio recorded and research team also took notes during the workshops.

4.5.3.1.1 Participant Selection

The potential participants to the workshops were selected in collaboration with the principal informant. The participants invited were regularly involved primarily with the landside supply chain and were in management or coordination position. A large proportion of the participants invited had already contributed to Stage 1: Exploration and expressed interest in being involved in joint discussions. The invitations to participate in the workshops were sent by email and included information on the agenda, and the executive summary of the report prepared by the researcher.

The choice to include managers and coordinators as opposed to drivers, who were experiencing first-hand the effects of congestion was driven by several considerations:

- First, the managers and coordinators had responsibilities in the commercial and operational areas of the companies they represented and were experienced in their roles.
- Second, they were on relatively similar positions in their companies' hierarchy therefore providing relatively similar power positions in discussions.
- Third, managers and coordinators typically had decision-making responsibility and authority regarding many of the issues planned for discussion.

The participant selection therefore tried to address issues regarding democratic involvement of participants in an inter-organisational context.

4.5.3.1.2 Workshop Structure

The workshops were organised on the terminal operators' premises in meeting rooms with projectors and support for presentations in Microsoft PowerPoint format. The participants were provided with a printed copy of the agenda, the report executive summary and worksheets. See Appendix H for agenda exemplar and Appendix I for worksheet exemplar.

The workshops were structured in 3 steps: aligning perspectives on congestion challenges, developing a common vocabulary, and the co-design of landside congestion management mechanisms. The researcher conducted the workshops accompanied by at least one member of the supervisory team.

The **perspective alignment** aimed to align stakeholders' perspectives and facilitate mutual understanding amongst participants. This involved round-table discussions, used as probing tools (Brandt, Binder and Sanders., 2012), where participants were invited to share their experiences, perceptions and understanding of the consequences of congestion on their operations, the potential causal factors, and the approaches employed to address this issue. It was expected that many issues raised during the workshops would have already been documented by the researcher in individual interactions. However, sharing the issues in a broader group setting could prompt feedback from other participants. The participants were also asked to discuss the congestion mitigation approaches taken within their own firms and the effects these had.

The researcher expected some degree of tension and frustration amongst participants, particularly between the terminal users and the terminal staff. This was primarily related to the fact that congestion was primarily treaded as a problem of the place of emergence, the terminal.

Consequently, it was considered likely that stakeholders' arguments could be influenced by accumulated emotions. Unless the emotions or frustrations are exposed, they can continue to affect the subsequent development of the discussions (De Bono, 2017). Therefore, after stakeholders were encouraged to share their thoughts, perceptions and frustration regarding congestion, a coffee break was scheduled to reduce and defuse the accumulated tension.

The next step, **developing a common vocabulary**, aimed to prime participants attention towards the broader supply chain. This stage involved the research team's presentation of the results that emerged in the exploratory data analysis and simulation modelling as well as a synthesis of the observations and semi-structured interviews. It was considered likely that participants would have an in-depth understanding of their organisations' internal workings but may not have the same understanding of the broader supply chain context. This idea is represented in Figure 25 with the "*blind and the elephant fable*" illustration. Therefore, the purpose of the researchers' presentation was to reveal actions and consequences in the context of the supply chain and focus the attention and thinking of participants on the consequences of approaches beyond than their own organisational boundaries.

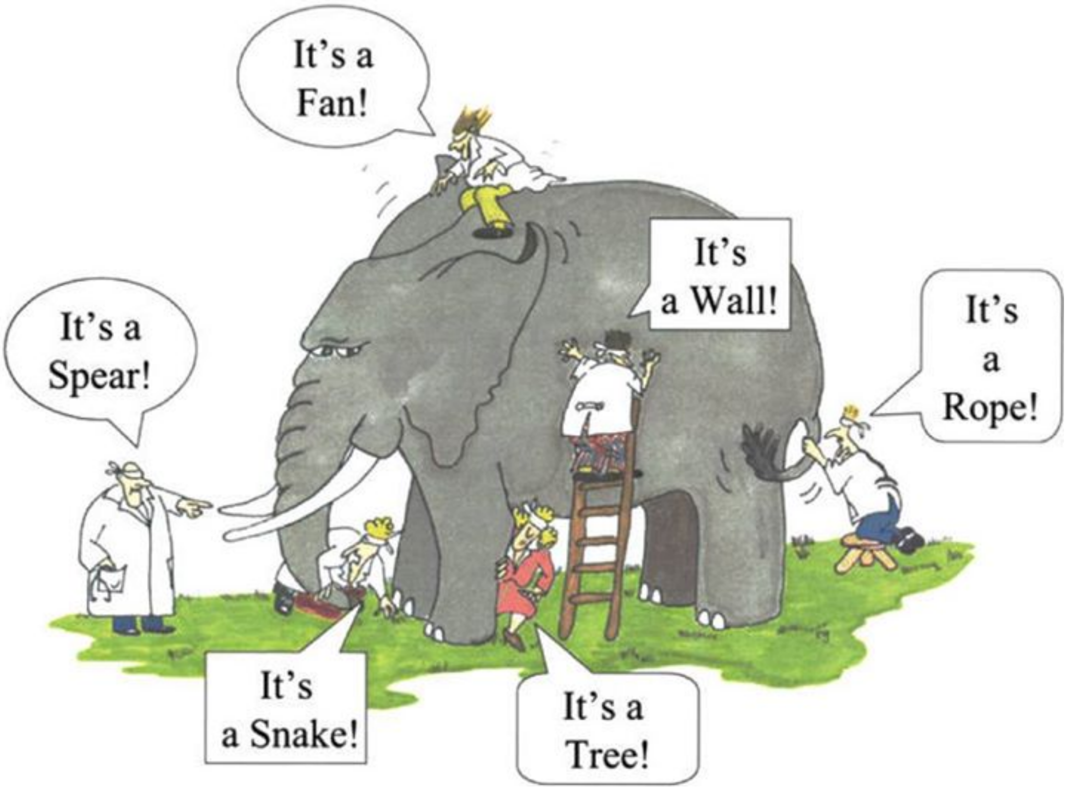


Figure 25 The Blind and The Elephant as Parallel to Perspectives on Congestion (Source: https://www.patheos.com/)

Finally, the **co-design stage** aimed to facilitate the joint exploration and design of approaches to mitigate landside congestion, building on the mutual learning and understanding from the previous two stages. The participants were encouraged to develop mechanisms addressing coordination, information sharing and digital technologies for three reasons: (1) from a pragmatic perspective, the implementation time of coordination or information sharing mechanisms is relatively shorter compared to infrastructure and equipment investments, and therefore increases the probability that Stage 3: Evaluation can capture both qualitative and quantitative impacts of the participatory design; (2) the relatively lower cost of implementation can increase the likelihood of mechanism implementation; (3) the exploration of information sharing and behavioural changes for coordination opens up the possibility to discuss the applications and feedback required for the effectiveness of mechanisms.

In summary, the data collected during stage2: design workshops aimed provide the input for analysis in order to capture joint understanding of the participants' perceptions and facilitate the alignment of perspectives and the development of a common vocabulary amongst participants.

The next section describes the data collection procedures employed in Stage 3: Evaluation.

4.5.4 Stage 3: Evaluation Data Collection

Stage 3: Evaluation included two main components: the evaluation of the effectiveness of the participatory design approach and the impact evaluation. The evaluation of the effectiveness of the participatory design approach was accomplished using qualitative data collected during Stage 2: Design Workshops and Stage 3: Evaluation semi-structured interviews collected 3-6 months after the workshops. The impact evaluation was accomplished using the data collected in the evaluation semi-structured interviews, and where possible and available, using quantitative data collected from weighbridges. The data analysis techniques deployed on the data emerging from Stage 3: Evaluation will be discussed in Section 4.6.3.

4.5.4.1 Approach Effectiveness

The evaluation of the effectiveness of the participatory design approach was accomplished using qualitative data collected during Stage 2: Design Workshops and Stage 3: Evaluation semi-structured interviews collected 3-6 months after the workshops.

The qualitative data collected during Stage 2: Design Workshops was analysed to understand the impact of the participatory design approach on the participants. The interventions of participants where they were discussing their understanding of congestion, their role in the supply chain or cooperative approaches were considered of interest in evaluating the effectiveness of the participatory design approach.

The evaluation semi-structured interviews aimed to understand the impact the workshops had on the participants and their work situation. These interviews were conducted over the telephone. The participants in the Stage 1: Exploration and Stage 2: Design Workshops were invited to the Stage 3: Evaluation interviews. Five respondents from Case A, two from Case B and four from Case C participated in Stage 3: Evaluation. All respondents, with one exception in Case C, had participated in Stage 1: Exploration and Stage 2: Design Workshops within their respective cases. The interviews lasted less than 30 minutes. The question frame for this stage centred on three categories of questions: the evolution of landside congestion, mechanisms implemented and their impact, respondents' perception changes with regards to the supply chain.

- Questions on the **evolution of landside congestion** aimed to understand whether a qualitative difference in congestion prior and after the workshops from the respondents' viewpoints.
- Questions regarding **the implementation and impact of landside congestion management mechanisms** sought to uncover whether the mechanisms designed during the workshops or new mechanisms to address congestion were used and whether they were perceived to be effective. An implementation of landside congestion management mechanisms following the workshops was not a mandatory requirement. However, in the majority of cases, workshop participants expressed agreement and interest in implementing some of the emerging mechanisms. Therefore, capturing perceptions regarding their effectiveness could yield valuable insights. Furthermore, the researcher expected some degree of influence between questions regarding the evolution of congestion and mechanisms implementation.
- Finally, the change in **respondents' perception of other supply chain participants and the supply chain as a whole** was investigated. The aim of these questions was to explore the whether the respondent's perception of understanding of the supply chain and other stakeholders has evolved as a result of the workshops.

4.5.4.2 Design Implementation Impact

The impact evaluation was contingent on the participants' actions and interest in the implementation of the designs emerging during the research, or implementation of other congestion mitigation mechanisms subsequently to the workshops. The implementation impact was gauged using quantitative data and through questions in the evaluation semi-structured interviews

Where landside congestion management mechanisms were implemented and the researcher was granted access to quantitative data similar to that collected in the previous stages (i.e. weigh-bridge or truck geo-positioning data), these data were analysed to evaluate the impact of the congestion mitigation approach implemented. The questions regarding the implementation and impact of congestion mitigation mechanisms presented in Stage 3: Evaluation semi-structured interviews presented in Section 4.5.4.1 were used to explore the impact of the designs.

In summary, the data collected as part of Stage 1: Exploration aimed to generate input for the analysis of the effectiveness of the participatory design process on the participants' understanding of congestion and on the mechanisms, tools and techniques for its mitigation.

The next section details the data analysis procedures utilised during this research.

4.6 Research Design: Data Analysis Procedures

This section details the data analysis procedures utilised in each stage of the research. A coding process drawing on the principles of grounded theory was utilised to analyse the qualitative data emerging from each research stage. Exploratory data analysis was used on quantitative data collected in Stage 2: Design Workshops and stage3: evaluation. Simulation modelling was used in Stage 2: Design Workshops.

4.6.1 Stage 1: Exploration Data Analysis

This section presents the data analysis procedure utilised in Stage 1: Exploration which consists of the coding approach drawing on principles of grounded theory employed on the qualitative data.

4.6.1.1 Coding Drawing on Principles of Grounded Theory

Qualitative data was analysed using a coding approach drawing on principles of grounded theory (Strauss and Corbin, 1990). Coding qualitative data assists in making sense of the large volume of data gathered during collection (Parker and Roffey, 1997). Grounded theory based approaches provide a methodology that can unpack the complexity of modern supply chains and the interactions of individuals within the whole (Randall and Mello, 2012). Ultimately, a holistic, inductive understanding of the phenomena under study is created by exploring the participants' perspectives (Charmaz, 2006). Grounded theory approaches are also recommended when relatively little is known about the topic of interest (Celsi, Rose and Leigh, 1993). Research on the factors conducive to the appearance of congestion, particularly at a supply chain level and focused on information and technology related aspects is relatively scarce, making a grounded-theory based approach a suitable methodology in this case.

The qualitative data collected across the cases during each stage of the research was pooled and analysed using a coding process drawing on the principles of grounded theory. When discussing the properties and dimensions of the various emerging categories, the researcher also evaluated whether the properties and dimensions were present across the cases or only emerged from one particular case.

The grounded theory tools and techniques that were used to analyse qualitative data including open, axial and selective coding, constant comparison as well as analytical memos and conceptual diagrams. The unit of analysis was the entirety of the qualitative data collected during this case study research. The interviews and workshops were partially transcribed by the first author of the paper to aid in the coding process. Open coding was applied at a sentence level. The process of open coding broke down data into individual parts that are then examined for similarities and differences (Strauss and Corbin, 1990). Wherever events or happenings shared common characteristics with previously coded events or happenings, these were placed under the same code. Codes were compared for properties or dimensions through constant comparison (Strauss and Corbin, 1990; Miles and Huberman, 1994). Figure 26 provides an exemplar of the open coding.

216 *stuff in our mill but not the operating parameters within // People gotta be prepared to come to*

217 *whatever communication forum we got in and, to deliver certain KPI or performance target, we got*

Joint stakeholder meetings

218 *to work out what are the measures for that and then there's got to be some data sharing to enable*

219 *that // If you're not going to track that, you won't know if that's working for you // It's about the data*

Performance measurement

220 *capture, the data provision, communication mechanism, and feedback mechanisms, it's common*

feedback mechanisms

221 *business practice I would have thought // It's about cross- boundary cross -organisation, do we do*

222 *we set up an environment where we are happy to share information because in the end, we all win*

Inter-organisational communication

223 *because the supply chain becomes most efficient as it can be // No good two parties out of a 5 party*

224 *or 6-party supply chain getting together saying we'll do right when there's four parts of a 6-part*

Stakeholder involvement

225 *supply chain that can go wrong // To date I'm not aware that that environment is going // In the*

Inter-organisational communication

226 *absence of having everyone together than [the terminal operator] are the only ones that hold all the*

Terminal central player

227 *information // But if that information is available to all port users, in this supply chain, then we can*

Information availability

228 *have more meaningful discussions.*

Figure 26 Open Coding Exemplar

The open coding process resulted in 411 open codes. Axial coding was used once the open coding process was completed with the purpose of forming developed categories and generating links between the different properties and dimensions of the data. Figure 27 provides an example of the axial coding for the INTERDEPENDENCE OF OPERATIONS axial code.

In total, 21 axial codes emerged during this stage. Selective coding was then employed to refine and integrate the resulting categories from the axial coding process. Three core categories emerged during this process: CONGESTION FACTORS, THE ROLE OF INFORMATION SYSTEMS and CONGESTION IMPACTS AND CONSEQUENCES. The core categories and associated axial codes are summarised in Figure 28.

Open Codes	Axial Code
Stage 1: Exploration: "inside vs outside", "the boat might not come back", competitive behaviour, competitors closure affecting deliveries, congestion challenges, congestion not seen in isolation, congestion shifting, core supply chain objectives, delivery slow-down, equipment relocation, fragmentation, frequent vessel arrivals, full supply chain, internal fragmentation, interruptions implications, just in time production, misaligned operations, miscommunication implication on congestion, mutual benefit, night-time staff availability, off-site queuing, operating hours misalignment, operational bottleneck, operational complexity, operational control, production and transport fragmentation, production changes affect balance, production distance to terminal, production fluctuation, production instability, production quality management, production restrictions, quality variation causes, reducing demand, resource quality affecting production, ripple effect, rostering challenges , seasonal influences, shipping schedules changes, staff availability, stock management, supply chain importance, terminal as intersection point, terminal available 24/7, their business impacting my business, throughput increase consequences, transport management **Stage 2: Design Workshops:** congestion is a by-product, driver preference, harvesting operations affecting congestion, port responsibility to community, production changes affecting congestion, production-transportation misalignment, transport and production relationship	Interdependence of operations

Figure 27 Axial Coding Exemplar

Analytical memos and conceptual diagrams were used by the researchers to help in the development of theory, as immersion in the data tends to facilitate the emergence of thoughts, relationships or ideas (Neuman, 2007). The results were integrated following each analytical stage through brief discussions on preliminary results.

CONGESTION FACTORS	THE ROLE OF INFORMATION SYSTEMS	CONGESTION IMPACTS AND CONSEQUENCES
Infrastructure Limitations	*Monitoring Compliance and Operations*	*Increased Costs*
Interdependence of Operations	*Communication Enabler*	*Frustration*
Operational Disruptions	*Information Sharing*	*Uncertainty*
Limited Coordination	*Decision Support*	*Compliance Management*
Misaligned Incentives	*Information Asymmetry*	*Competitiveness*
Supply Chain Inflexibility	*Visibility Enabler*	*Resilience*
Performance Expectation	*Behavioural Expectations*	
	Performance Gains	

Figure 28 Emerging Core Categories

In summary, the data analysis performed as part of Stage 1: Exploration aimed to provide a baseline understanding of the participants perceptions of congestion and factors contributing to it, as well as insights into congestion impacts and potential mitigation mechanisms.

The data analysis procedures employed in Stage 2: Design Workshops is described next.

4.6.2 Stage 2: Design Workshops Data Analysis

The data analysis procedures utilised in this research stage included discrete event simulation modelling, exploratory data analysis for the quantitative data and a coding process drawing on the principles of grounded theory for the qualitative data.

4.6.2.1 Discrete-Event Simulation Model of Terminal Truck Unloading Operations

The discrete-event simulation model of the bulk cargo marine terminal truck unloading operations aimed to: (1) improve understanding with regards to the impact of stochastic components (mainly truck arrival, unloading and weighing times) on the overall unloading performance and (2) evaluate the sensitivity of the truck unloading operations at the terminal to changes in these stochastic components or terminal setup.

As the impact of stochastic components was considered critical, the truck and weigh-bridge data collected were fitted intro probability distributions which would be sampled for every iteration of the model and every truck (Section 4.6.2.1.2). The model's logic (Section 4.6.2.1.3) was developed based on the existing terminal unloading process (Section 4.6.2.1.1). The model's assumptions (Section 4.6.2.1.4) and outputs were validated both through comparison with the empirical data and through discussions with terminal staff (Section 4.6.2.1.5). The model could only be generated for the marine terminal in Case A as sufficiently granular data were available in this case.

The envisioned outputs of the model were a series of scenarios that would illustrate the expected impacts of variations landside congestion management methods in the form of changes in the stochastic components or terminal setup. The model's outputs served as a discussion point with and between participants in the workshops. Given the applied nature of the research, it was highly likely that those who had to make sense of the model and its results were the terminal's and users' staff which had a diverse demographic and socio-economic backgrounds. Therefore, the simulation model was designed with simplicity in mind to ensure that it adequately serves its purpose as a discussion point with and between participants.

The supply chain and terminal unloading process that inspired the simulation model logical flow is briefly described in the next subsection.

4.6.2.1.1 Terminal Processes

The terminal receives regular deliveries from the two customers via three production facilities using trucks that operate in a closed loop between the production sites and the terminal. Each customer operates two types of trucks with a maximum payload of 32 and 45 tons. Formal coordination between customers was minimal. Over the last 5 years, the number of deliveries at the terminal have increased by close to 500%. Following the increase in terminal throughput, congestion ensued impacting the service time and truck utilisation.

The terminal unloading process is sequential and starts at the weigh-bridge where drivers get a record of the gross weight of their truck and an arrival timestamp. Next, trucks head on the wharf where they can unload on two hydraulic platforms that lift the truck forcing the product to slide into a common container. The wood chip container is emptied by a common conveyor system to the appropriate customer stockpile. Because the conveyor belt system is shared for both customers' products, concurrent unloading of trucks belonging to two different customers cannot take place. Once trucks are emptied and back on the ground, they are driven once more on the weigh-bridge for an empty weight reading and a departure timestamp. The difference between the two timestamps marks the truck turnaround time. The total terminal throughput and the average truck turnaround times are the two main indicators followed by the terminal and customers.

The congestion experienced by the terminal users is not extreme. However, the close proximity between the mills and the terminal means significant changes in the terminal turnaround time can impact on the efficiency and utilisation of the transporters' equipment and the chain as a whole. A truck can be processed at the terminal without interruptions in 10 to 12 minutes. Currently, average turnaround times is approximately 22-24 minutes and have been steadily increasing as volumes increased. More than 60% of turnaround times are below 25 minutes and approximately 35% of trucks are unloaded within an hour of arrival. The remaining trucks have turnaround times larger than 60 minutes and can reach 120-150 minutes. Considering the round-trip driving time between the production facilities and the terminal and the drivers' 12-hour working window, an increase in terminal turnaround time over 25 minutes impacts the number of daily deliveries that can be achieved. Specifically, trucks running on a 40-minute round-trip loop may only be able to achieve 10 instead of 11 daily deliveries, while trucks running on a 90-minute round-trip loop may only achieve 5 instead of 6 daily deliveries. Given the economic impact of congestion, both the terminal operator and its users were interested in understanding the potential options to manage congestion as well as their impact over a range of throughput scenarios. Consequently, the 25-minute mark was considered as the threshold for truck turnaround time reliability in the performance measurement.

4.6.2.1.2 Model Inputs

The distribution fitting process was undertaken for weigh-bridge data on inter-arrival times (IAT) and truck payloads and for the GPS data for understanding the duration of the unloading and weighing-out processes. Fitted distributions were used instead of empirical distributions because of their known probability properties. Empirical distributions may miss certain values due to sampling which may not be representative of the real-life situation. Probability distributions overcome this drawback by assign a probability to values not observed in the empirical distribution.

Table 10 Distribution Fitting Results

Data	**Unload**	**Weigh-Out**	**IAT**	**Truck (I-A)**	**Truck (II-A)**	**Truck (I-B)**	**Truck (II-B)**
Offset	5.5	0	-0.5	19	0	19	29
Output Distrib.	LOGN (5.16, 3.97)	N(3.46, 1.68)	G(1.49, 6.97)	B(9.77, 6.55)	N(38.7, 1.18)	B(10.3, 27.7)	B(10.6, 19.2)
Sum of Sq. Error	0.002	0.016	0.002	0.007	0.004	0.004	0.022

IAT = Inter-Arrival Time; LOGN = Lognormal distribution; N = Normal distribution; B = Beta distribution.

Table 10 illustrates the output of the distribution fitting procedure. The sum of squared errors of the fitted distribution and its parameters compared to the empirical distribution for a range of distributions. The distribution with the smallest sum of squared errors was selected and used as input in the discrete event simulation model.

The simulation model logical flow is described next.

4.6.2.1.3 Model Logical Flow

The simulation model is implemented in Python programming language. The model's algorithm follows closely the unloading process observed at the terminal and is described in Figure 29. The model records waiting times of trucks in three separate stages: waiting prior to unloading – due to no available unloading ramp, waiting to unload – due to unavailable conveyor belt capacity, and waiting in lane at exit– if the weigh-bridge is in use. The truck turnaround time is measured from when the truck enters the system until it exits and contains the waiting time as well as the unloading operation and the truck drive time. Truck arrivals at the terminals represent the events and are calculated based on inter-arrival times (IAT) drawn from empirical data collected from the terminal operator.

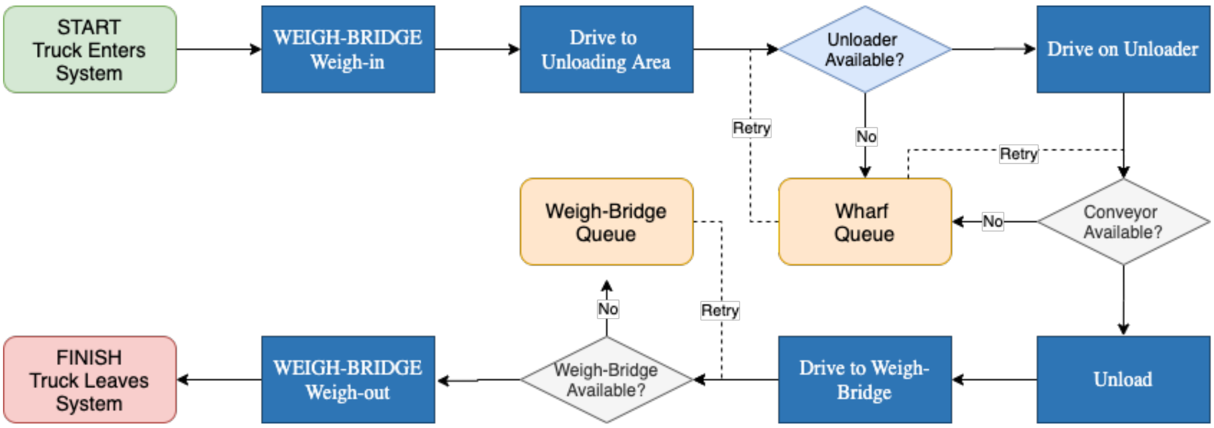


Figure 29 Terminal Simulation Model Flow

The quantitative input data for the simulation model were collected from two sources – the terminal weigh-bridge database and truck telemetry data supplied by one of the transport operators. The weigh-bridge database containing 9 months' worth of truck arrivals at the terminal, between January 1st and September 30th, 2017 which included information on truck arrival and departure times, and truck weights. These data were supplied by the terminal operator and its users. Operational times from the weigh-bridges, and unloading ramps were recorded using truck telemetry data. Each site was geo-fenced and recorded truck information, entry and exit times from area. The geo-fence data covered 3 months of operations, between June 1st and September 30th, 2017.

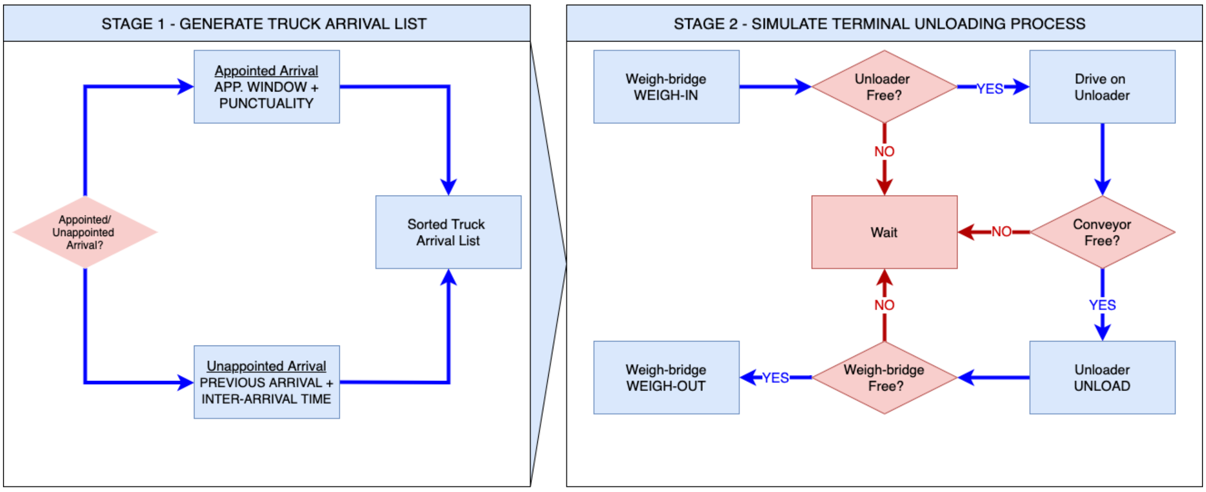


Figure 30 Terminal Simulation Model Flow - System Parameters and User Behaviours

The model was subsequently extended to simulate additional scenarios relating to the implementation of a terminal appointment system. The logical flow is detailed in Figure 30. The model thus required a two-stage approach. In the first stage, the appointed and non-appointed truck arrivals are generated and sorted. In the second stage the individual trucks are processed in the same process as shown in Figure 29.

The model's specifications and assumptions are discussed next.

4.6.2.1.4 Model Specifications and Assumptions

The simulation model primarily centres on the truck unloading process and covers operations from the truck's arrival at the weigh-bridge prior to unloading until the truck's departure from the weigh-bridge, after it had been unloaded. The model's boundaries were mainly determined by the data made available by the terminal operator and its users. The available data used for the simulation model were collected from the weigh-bridge system and geo-fence visit durations using truck-mounted geo-positioning systems (GPS) units.

- The landside operations outside the terminal gates could not be included as the range of variables that could impact the time a truck spends outside the terminal was too wide. Some examples include: distance variations, truck loading duration variations, fatigue management breaks, breakdowns. Furthermore, since only one operator used a GPS monitoring system, insights on the other parties' behaviours were limited.
- The marine-side of the operations was not included as historical vessel arrival data were not available.
- Product storage operations were only partially included. The unloading ramps used by the trucks were connected by a common conveyor belt system that delivers the product from a hopper to a stockpile. Because of conveyor capacity limitations two trucks cannot unload at the same time. The actual storage capacity of the terminal was not included due to limitations in vessel arrivals data as vessel arrivals indicate when and by what amounts the storage capacity is being depleted.

Other assumptions of the simulation model are as follows:

(1) The terminal and customers operate 24 hours per day, 365 days per year; Operations are not interrupted due to maintenance, breakdowns or weather events.
(2) The terminal has infinite product storage capacity and accepts all truck deliveries at any time; Vessel arrivals at the terminal do not affect the truck unloading operations.
(3) Trucks incur no waiting prior to entering the system.
(4) Truck arrivals are independent of one another.
(5) Breakdowns, breaks, shift-changes which the authors could not account for.
(6) Truck are served in the order in which they arrive – first-come first served.
(7) Both unloading ramps have the same capacity and similar operational speeds following the distribution described above.
(8) Unloading a 32-ton payload truck is 2 minutes faster than unloading a 45-ton truck.
(9) If one unloading ramp has completed more than 60% of its unloading cycle the other can begin unloading if the two trucks being unloaded are carrying the same type of product(s). Otherwise, concomitant unloading (m) can take place if one ramp has completed 80% or more of its unloading cycle.
(10) The driving time between the weigh-bridge and the unloading ramps is held constant at 1 minute on arrival (τ_1) and 2 minutes on departure (τ_2).
(11) The weighing-in time (σ) was estimated at 1.5 minutes per truck following on-site observation and telemetric data analysis as the weighing-in time is not captured by the weigh-bridge software.

The validation of the model is presented next.

4.6.2.1.5 Model Validation

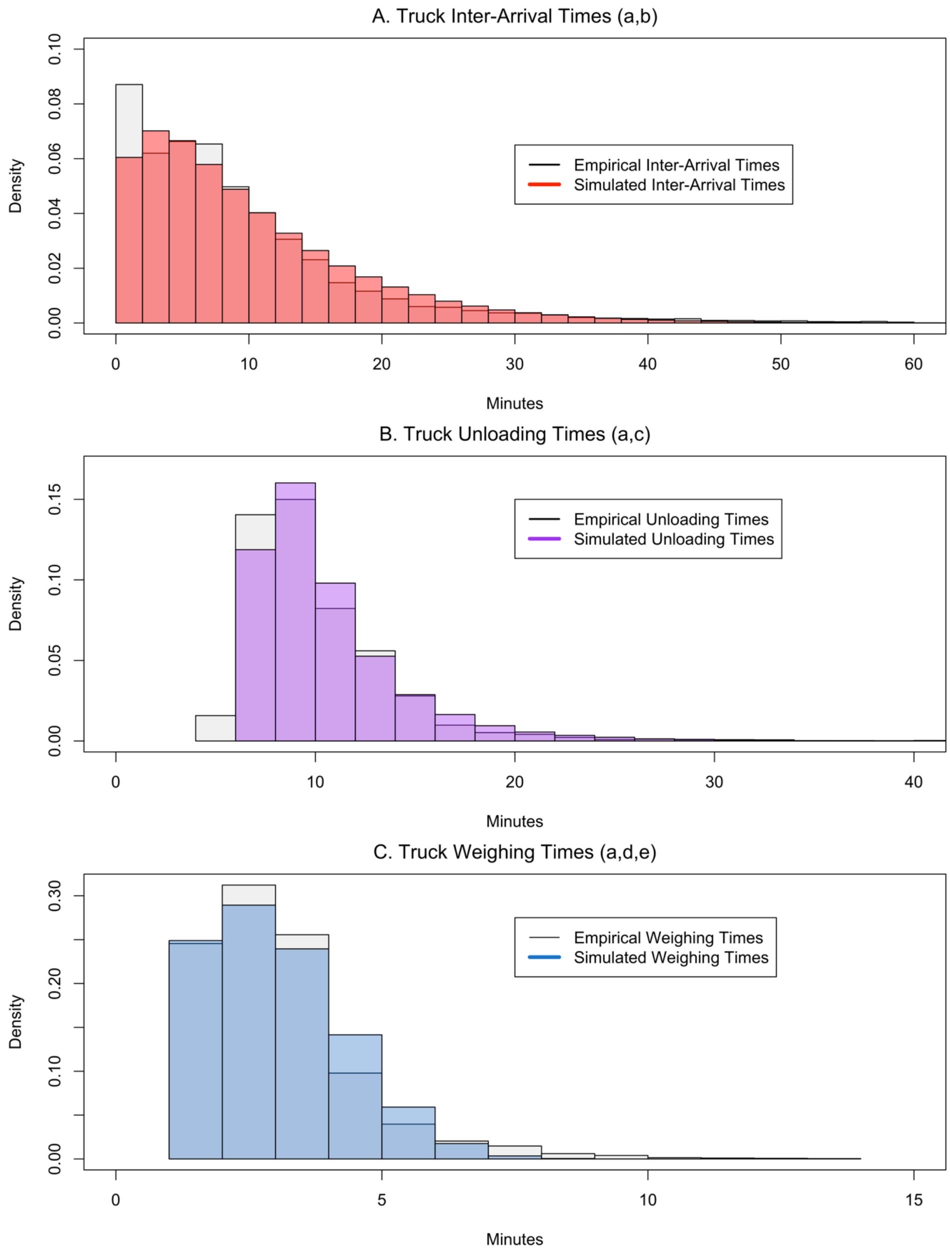
Due to their importance in the accuracy of representation of the simulation model, it was critical that the fitted and empirical distributions would not be significantly different. In this sense, the fitted and empirical distributions were tested using a Chi-Square test.

Table 11 Fitted and Empirical Distribution Validation

Input	Chi-Square Test p-value
Inter-arrival Times	0.287
Unloading Times	0.106
Weighing Times	0.385

The Chi-Square test results are summarised in Table 11. The results indicate that there are statistically significant differences between the fitted and empirical distributions of the three components – truck inter-arrival, unloading and weighing times.

The logical flow, model's inputs and outputs were compared with the actual situation to evaluate the model's representation accuracy. The model was presented to the terminal staff who were asked to provide feedback on the input parameters, particularly for those where datasets were unavailable, on the model flow (using a figure similar to Figure 29, p. 99) and on the model's output. Changes suggested by the staff were implemented accordingly and the model was iteratively refined.



[a] Data spans from 01.06.2017 to 30.09.2017; [b] Truck Inter-Arrival Times included 15,622 weigh-bridge entries under 100 minutes (44 observations over 100 minutes were excluded; [c] Truck Unloading Times include geo-fence 6709 entries (maximum value 118 minutes, graph limited to maximum 30 minutes for legibility); [d] Truck Weigh-Bridge Times include 6752 entries

Figure 31 Case A - Model Validation - Empirical vs Simulated Inputs

The model's input distribution parameters (inter-arrival times, truck unloading duration and weighing-out duration) were also validated against the empirical data. Figure 31 illustrates the simulated inputs and the empirical distributions. The simulated and empirical truck unloading times included in Figure 31 B only for truck type II-A as the geo-fence data collected from the transport contractor only covered this type of truck. The simulated distribution appears to have a larger proportion of low unloading time durations when compared to the empirical distribution. In Figure 31 C, a similar, although less pronounced pattern, can be seen regarding the truck weighing times. This pattern may be partially caused by the recursive implementation of the probability generator function of the simulation model. The model uses the Python "random" module to generate pseudo-random numbers and then to apply an offset coefficient to align the simulated and empirical distributions.

The next section discusses the exploratory data analysis procedures utilised in this research.

4.6.2.2 Exploratory Data Analysis

The exploratory data analysis consisting of statistical summarisation, data visualisation and extreme value elimination was undertaken a number of times until multiple aspects of the data were reviewed, and trends and relationships were identified and explored. The exploratory data analysis was performed primarily using the R statistical software and Microsoft Excel. The data was first visualised to provide an overall impression of its features and reveal extreme observations. Extreme observations were determined based on their possibility of occurrence in real-life. For example, a truck turnaround time of 1,345 minutes was deemed impossible since the longest shift a truck driver is legally allowed to work is 12 hours, or 720 minutes. Therefore, while the truck may have been left on site for more than 12 hours, the driver and truck would not be in service. Once the visualisation and extreme values elimination cycles were completed the data were summarised to facilitate comparison across different time-frames for the within-case analysis and case study field sites in the cross-case analysis.

The quantitative data collected during each research stage were analysed within the context of each case study. The results of these analyses were compared across the three cases. For example, the truck turnaround times distributions in Case A were visualised and the statistic descriptors discussed. Subsequently, the truck turnaround time distributions in Cases B and C were also analysed. The values of the statistic descriptors were compared along with the shapes of the distributions in each case.

Weigh-bridge data was available across the three case studies and was analysed with similar techniques. Weigh-bridge data included information on truck arrival and departure times, truck identifiers, payload, weights and origin.

- **Truck turnaround times** calculated as the difference between the weigh-in (arrival) time of a truck until weighing-out (departure) time of the truck were explored and visualised using histograms. Turnaround times were the metric used by terminal staff to understand the measure of congestion. This performance indicator is also used by the literature (e.g. Li *et al.*, 2018; Torkjazi, Huynh and Shiri, 2018). In the absence of detailed waiting time information, the truck turnaround times are a proxy for congestion as higher times typically translate in higher waiting times. The turnaround times were explored primarily using histograms, and in relation with the number of trucks on site and the daily throughput, using scatterplots
- The **truck inter-arrival time (IAT)** was also explored for the three case studies. Truck inter-arrival time represents the difference between two consecutive truck arrivals measured as the difference between two weigh-in times of two trucks. The inter-arrival time is one of the main inputs for the terminal simulation model and is typically used by researchers in simulation modelling studies (Huynh, 2009; Ramírez-Nafarrate *et al.*,

2017). Inter-arrival times were primarily explored using histograms. Figure 32 illustrates an example of inter-arrival times histogram.

- The **unloading duration**, **weighing-in** and **weighing-out durations** in the geo-fenced areas recorded by the GPS data processing software were also visualised, cleansed and summarised. Two main challenges were encountered in analysing these data. First, a truck is required to use the weighbridge when arriving and when departing. Discussions with terminal staff and researcher observations revealed that while the process for weighing-in entails only swiping and RFID card, the process for weighing-out entails the driver physically walking out of the truck to a nearby booth where they have to fill out a paper docket or receipt. Therefore, it was expected that the weighing-in process would take less time than weighing-out. Second, the researcher observed when sorting the data by truck and in ascending order of time that two adjacent entries for the same type of operation could sometimes be observed. While in the case of weigh-bridge visits this was expected, a weigh-in visit is proceeded by a weigh-out, this was not expected for unloading, particularly when the time difference between two observations was very small (under 5 minutes). The data were cleansed and aggregated where appropriate to ensure that the resulting distributions are as close as possible to the empirical situation.

The data collected during Stage 3: Evaluation of Case A were explored in a similar fashion to the data used in Stage 2: Design Workshops. The statistical significance of differences between the experiment and control were tested using the appropriate parametric or non-parametric tests (Fay and Proschan, 2010).

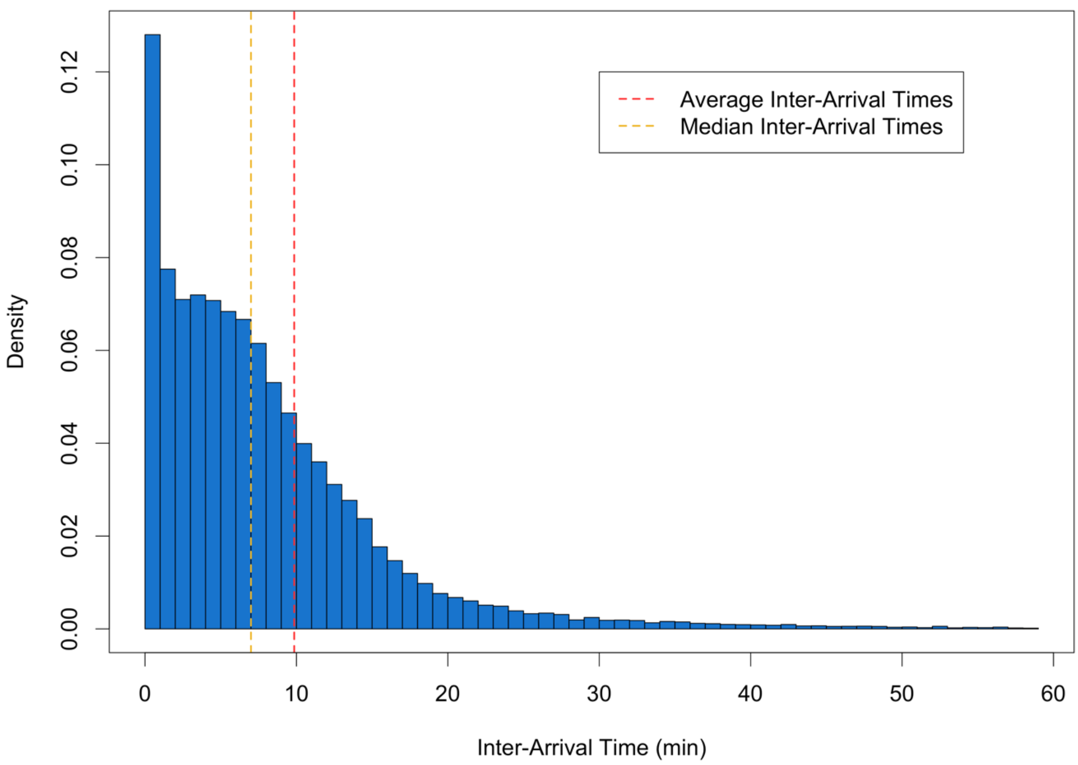


Figure 32 Case A - Truck Inter-Arrival Times
(Data range from 01.01.2017 to 30.09.2017)

In summary, the exploratory data analysis involved iteratively visualising data, eliminating extreme values and identifying meaningful trends and patterns. The main aspects investigated revolved around truck turnaround and inter-arrival times for weigh-bridge data. Geo-fence data were cleansed, categorised and used in the distribution fitting process.

The coding process drawing on the principles of grounded theory employed in the analysis of the qualitative data collected during Stage 2: Design Workshops is described next.

4.6.2.3 Coding Drawing on Principles of Grounded Theory

The coding process drawing on the principles of grounded theory (see Section 4.6.1.1 for a complete description) was employed on the data resulting from the workshops. The resulting codes and categories were compared with those resulting from Stage 1: Exploration.

In summary, the data analysis performed during Stage 2: Design Workshops aimed to capture joint understanding of the participants' perceptions and facilitate the alignment of perspectives and the development of a common vocabulary amongst participants.

The data analysis procedures employed in Stage 3: Evaluation is discussed next.

4.6.3 Stage 3: Evaluation Data Analysis

This section discusses the data analysis procedures utilised in Stage 3: Evaluation. A coding approach drawing on the principles of grounded theory was used on the qualitative data emerging in Stage 3: Evaluation. It was not clear from the onset whether the designs emerging from the workshops would be implemented. If that were the case and quantitative data were available, these would be analysed using exploratory data analysis (including statistical summarisation, testing and visualisation techniques).

4.6.3.1 Approach Effectiveness

The coding approach drawing on the principles of grounded theory (see Section 4.6.1.1) was employed on the data resulting from Stage 2: Design Workshops and the data emerging from the evaluation semi-structured interviews.

4.6.3.2 Design Implementation Impact

The coding approach drawing on the principles of grounded theory (see Section 4.6.1.1) was used on the data emerging from the evaluation semi-structured interviews where congestion mitigation approaches were implemented by the participants.

Similarly, where post-implementation quantitative data were shared with the researcher, these were analysed using exploratory data analysis statistical summarisation and visualisation techniques described in Section 4.6.2.2. and with statistical tests for evaluating differences between distributions.

The next section presents the approach used to interpret and discuss the results of this research.

4.7 Research Design: Data Interpretation and Discussion

This section presents the iterative interpretive process adopted to produce the findings of this research from results. Next the approach adopted for discussing the results and emerging findings in relation to the research questions and the extant literature is discussed.

The interpretation process was iterative and comparative (Silverman, 2015) and was performed throughout the three stages of this research. Preliminary interpretations were drawn following the completion of Stage 1: Exploration and Stage 2: Design Workshops to strengthen the researcher's understanding of the semantic inter-relationships between the preliminary results. The outcomes of the preliminary interpretations are summarised at the end of each stage of the research. These preliminary interpretations helped focus the data collection and analysis in the subsequent research stages. Once '*theoretical saturation*' (Eisenhardt, 1989; Walsham, 2006) was reached a final interpretation was undertaken to produce the key findings of the research which are presented and discussed in detail in Chapter 6. The key findings helped answer the research questions and provided a platform for discussion in relation to the extant research literature.

Preliminary interpretations were drawn following the completion of Stage 1: Exploration and Stage 2: Design Workshops to strengthen the researcher's understanding of the semantic inter-relationships between the preliminary results. Axial and core categories emerged from the coding process drawing on the principles of grounded theory. These were treated as tentative categories (Charmaz, 2006). The results emerging from quantitative data analysis were also listed. The emerging categories were refined through a constant comparison with the data. Eisenhardt (1989) suggests three strategies to performing these comparisons: (1) selecting dimensions and categories and looking for group similarities and inter-group differences, (2) listing the similarities and differences between pairs of cases and, (3) dividing the data by source. Miles and Huberman (1994) also suggest counting the evidence, checking for the meaning of outliers, following up on surprise results as well as seeking for negative evidence.

The emerging preliminary interpretations helped shape the data collection and analysis of the subsequent stages. For example, in Case A, the terminal infrastructure was frequently mentioned as one of the leading causes of congestion at the terminal. This prompted the researcher to explore the duration of truck visits on each piece of equipment utilised. The exploratory data analysis revealed limited variability in the durations of truck visits. This was particularly the case for the weigh-bridge which was a piece of infrastructure that was often mentioned by some participants.

Conversely, findings obtained from analysing quantitative data revealed preliminary insights that were subsequently explored. In Case B, the researcher observed truck arrival patterns prior to the terminal opening times and the increased truck turnaround times of trucks arriving early as a result. This pattern prompted a discussion during the workshops on the consequences of individual decisions on the operations of the entire supply chain. As a result, multiple perspectives on the rational of individual decisions were shared during the workshop which contributed to a fuller understanding of the participants' business processes and interests.

Iterating between data and the emerging categories and quantitative results took place until '*theoretical saturation*' (Eisenhardt, 1989; Walsham, 2006). Reaching theoretical saturation meant that the iterative process of comparing data and categories and quantitative results revealed no additional new information. There were also practical boundaries to reaching theoretical saturation which pertained to the availability of participants and travel costs. A final interpretive step took place once theoretical saturation was reached to complete the interpretive cycle in order to produce the findings of this research. Two examples of how the interpretation process generated the findings of this research are provided. Primarily in Stage 1: Exploration, a large proportion of participants highlighted that infrastructure limitations were a factor if not the most important factor to congestion. However, quantitative data analysis results of infrastructure utilisation provided evidence that utilisation times were generally consistent and without significant variation. Therefore, contradiction emerged when comparing the results from the qualitative and quantitative analysis. This contradiction helped shape two of the findings of this research, KF-1 and KF-3. Thus, the impact of potential infrastructure limitations as a factor to congestion was recognised and at the same time the fact that landside congestion tends to manifest itself at terminals but not necessarily because only by factors within the terminal was highlighted.

A second example relates to the meaning of average measures of truck turnaround times. The average truck turnaround times were used across the stages of this research and across cases as a measure of congestion. However, surprisingly, in Stage 2: Design Workshops, during one workshop, one participant indicated that trucks should be unloaded in a set time, which they indicated as the average. Although this was one occurrence in the research, it prompted the researcher to revisit the previously collected data and categories and consider whether the average measures of truck turnaround times were in fact misconstruing the perception of congestion for the participants. As the qualitative data were re-examined, it became apparent that the assumption that the average is equivalent to a maximum threshold was prevalent across participants. This thinking process led to KF-4 and the generation of additional performance measures of truck turnaround times.

The findings of this research which included a model of congestion factors and a framework for participatory mitigation of congestion were discussed in the context of the research to reveal the conceptual, methodological and substantive contributions of this work. The discussion aimed to highlight the convergence, conflict or complementarity of the findings in relation to the literature. Some of the results obtained were also discussed in the context of the research literature. The discussion consisted of an assessment of the value of the findings of the research in relation to congestion factors, mitigation and the role of information systems in this context.

In summary, data interpretation was an iterative process undertaken across the three stages of the research until theoretical saturation was reached. A final interpretive step led to the emergence of the key findings of the research. The key findings and results were then discussed in relation to the extant research literature and the research questions of this work.

The next section contains the summary reflections of this chapter.

4.8 Summary Reflections

This chapter has provided a detailed description of the methodology used in this research to answer the research questions formulated in the previous chapter. The methodology adopted in this research was multiple case studies participatory design approach and involved the collection and analysis of qualitative and quantitative data.

In this research, a subjective ontology and an interpretivist epistemology were adopted. The methodology adopted in this research involved the conduct of three case studies using a participatory design approach. Each case centred on a bulk cargo marine terminal for forest products exports and the associated supply chains. The participatory design approach was used for each case and consisted of three stages: exploration, design workshops and evaluation. Stage 1: Exploration aimed to provide a baseline understanding generated primarily from the analysis of qualitative data of the participants perceptions of congestion and factors contributing to it, as well as insights into congestion impacts and potential mitigation mechanisms. Stage 2: Design Workshops to capture joint understanding of the participants' perceptions and facilitate the alignment of perspectives and the development of a common vocabulary amongst participants. The quantitative data collected in the previous stage were analysed using *simulation modelling* and *exploratory data analysis* techniques and the results were presented and discussed as part of the development of a common vocabulary. Furthermore, the workshops included a design component in which participants, using the common vocabulary, could develop congestion mitigation approaches for their supply chains. Stage 3: Evaluation aimed to explore the effectiveness of the participatory design process on the participants' understanding of congestion and on the mechanisms, tools and techniques for its mitigation.

Qualitative and quantitative data were collected and analysed in each stage of the participatory design approach. During Stage 1: Exploration, qualitative data were collected through site visits and semi-structured interviews. Quantitative data consisting of truck arrival records and truck geo-positioning data were also collected. Stage 2: Design Workshops consisted of 4 workshops across the 3 case studies. Qualitative data emerging from the workshops were collected. The quantitative data collected in Stage 1: Exploration was analysed using exploratory data analysis and simulation modelling. During Stage 3: Evaluation, qualitative data were collected through semi-structured interviews. Further quantitative data consisting of truck arrival records were also collected. The qualitative data emerging from each stage were analysed using grounded theory coding principles. Finally, the iterative interpretive process adopted to produce the findings of this research from results was presented long with the approach adopted for discussing the results and emerging findings in relation to the research questions and the extant literature.

The next chapter presents the results and outcomes of applying the methodology presented in this chapter. The results are presented for each stage of the research across the three case studies.

Chapter 5 Data Analysis and Results

5.1 Introduction

The previous chapter has presented the multiple case studies approach employed in this research. The multiple case participatory design approach consisted of three stages: exploration, design workshops and evaluation. Qualitative data was collected throughout the three stages and analysed using a coding process drawing on the principles of grounded theory. Quantitative data was collected in Stage 1: Exploration and Stage 3: Evaluation and analysed using simulation modelling and exploratory data analysis presented in Stage 2: Design Workshops.

This chapter presents the results and outcomes of applying the methodology presented in this chapter. The structure of this chapter is as follows:

- Section 5.2 discusses the analysis of the qualitative data emerging from the first stage of the research approach, Stage 1: Exploration. The qualitative data gathered through site visits and semi-structured interviews were analysed using a coding process drawing on the principles of grounded theory. This process led to the emergence of three core categories: CONGESTION FACTORS, CONGESTION IMPACTS AND CONSEQUENCES and the ROLE OF INFORMATION SYSTEMS. Insights regarding the main perceived congestion factors (infrastructure limitations and supply chain interdependence) were obtained during this stage. The role of digital tools in monitoring operations and compliance was highlighted in this stage. Potential limiting factors and expectations regarding information sharing were also discussed.
- Section 5.3 presents the analysis of the qualitative and quantitative data in Stage 2: Design Workshops. Qualitative data were analysed using a coding process drawing on the principles of grounded theory. This process led to the emergence of three core categories: CONGESTION FACTORS, CONGESTION IMPACTS AND CONSEQUENCES and the ROLE OF INFORMATION SYSTEMS. The quantitative data collected during Stage 1: Exploration were analysed using exploratory data analysis and simulation modelling. The analysis of the quantitative data was performed prior to the workshops themselves as part of the preparation for the workshops. The exploratory data analysis and simulation modelling contradicted the participants' beliefs that congestion was primarily caused by inadequate terminal infrastructure and supported the impact of the limited coordination had on the appearance of congestion. This stage facilitated the emergence of participant-constructed approaches to mitigate congestion. [8]

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[8] This section draws from Neagoe, M., Nguyen, H.-O., Taskhiri, M. S., Hvolby H-H and Turner, P "Exploring congestion impact beyond the bulk cargo terminal gate." Logistics 4.0 and Sustainable Supply Chain Management, Proceedings of HICL 2018 (2018): 63-82, Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P. "*Using Discrete-Event Simulation to Compare Congestion Management Approaches at a Port Terminal.*" Simulation Modelling Practice and Theory Journal, UNDER REVIEW and Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P (2019c) "Using Discrete-Event Simulation to Explore

- Section 5.4 presents the analysis of the data emerging from the third stage of the research approach, the evaluation. Both qualitative and quantitative data were analysed during this stage. Qualitative data were analysed using a coding process drawing on the principles of grounded theory. Quantitative data were analysed using exploratory data analysis. The evaluation provided evidence supporting the positive impact of the research approach on the development and positive impact of the participant-constructed approaches to mitigating congestion.[9]
- Section 5.5 presents the summary reflections of this chapter.

The next chapter discusses the key findings emerging from the analysis and interpretation of the data across the three stages of this research. The key findings are discussed and interpreted in this chapter in relation to the extant research literature and the research questions.

the Impact of User Behaviours on the Effectiveness of a Terminal Appointment System." In 33rd European Simulation and Modelling Conference, ESM 2019. EUROSIS-ETI

[9] This section draws from Neagoe, M., Hvolby H-H., Taskhiri, M. S., Nguyen, H.-O. and Turner, P (exp. 2020) "What's the hold up? A participatory design approach to understanding and ameliorating congestion at an Australian marine terminal". Maritime Economics and Logistics, UNDER REVIEW

5.2 Stage 1: Exploration

The results of Stage 1: Exploration resulted from the analysis of data collected from 25 interviews across the three case studies. The analysis process entailed the systematic coding to reduce the amount of data. The open, axial, and selective coding were applied as described in Section 4.6.1.1. First, the data were open coded. Subsequently, all codes were systematically revised through constant comparison which led to the emergence of the axial codes. Selective coding to identify the core categories was employed guided by the research questions and objectives. The three core categories and associated axial codes emerging from this process are discussed in the first part of this section. The relationships between the core categories are discussed next. Finally, the preliminary results emerging during this stage are presented.

5.2.1 Analysis and Preliminary Core Categories

This section presents the analysis and the preliminary core categories emerging from the coding process drawing on the principles of grounded theory. This analysis step consisted of open axial and selective coding of the data emerging from semi-structured interviews and produced a series of preliminary axial and core categories which are discussed below. The preliminary results obtained during this stage helped prepare for participatory design to optimise the range and diversity of perspectives and to find an area of commonality or common misunderstanding that can be targeted in the Stage 2: Design Workshops. The preliminary core categories emerging from this analysis stage were: congestion factors, congestion impacts and consequences and the role of information systems.

5.2.1.1 Congestion Factors

The CONGESTION FACTORS core category refers to aspects of terminal and supply chain operations that are conducive to the appearance of congestion. There were seven axial codes associated to this core category:

- *INFRASTRUCTURE LIMITATIONS* refer to terminal infrastructure, layout, processes and equipment that limit the number of trucks that can arrive, wait or be unloaded at the terminal at any one time.
- *INTERDEPENDENCE OF OPERATIONS* refers to technical aspects within and between supply chains that impact on truck arrivals at the terminal and terminal operations. These may refer to operating hours, compliance requirements, vessel arrivals.
- *OPERATIONAL DISRUPTIONS* refer to delivery suspensions at the terminal for breakdown, wood-chip contamination, weather events or delivery suspensions due to insufficient terminal or downstream supply chain capacity limitations.
- *LIMITED COORDINATION* refers to behaviours within individual organisations, between organisations and along the supply chain which lead to overlaps and operational clashes.
- *MISALIGNED INCENTIVES* refer to aspects that encourage individual or organisational behaviours which lead to the emergence of operational clashes within organisations and supply chains as well as between supply chains.

- *SUPPLY CHAIN INFLEXIBILITY* refers to technical limitations in the ability of individuals and organisations to make operational changes or decisions.
- *PERFORMANCE EXPECTATIONS* refer to the performance measures considered acceptable by individuals and organisations in the supply chain.

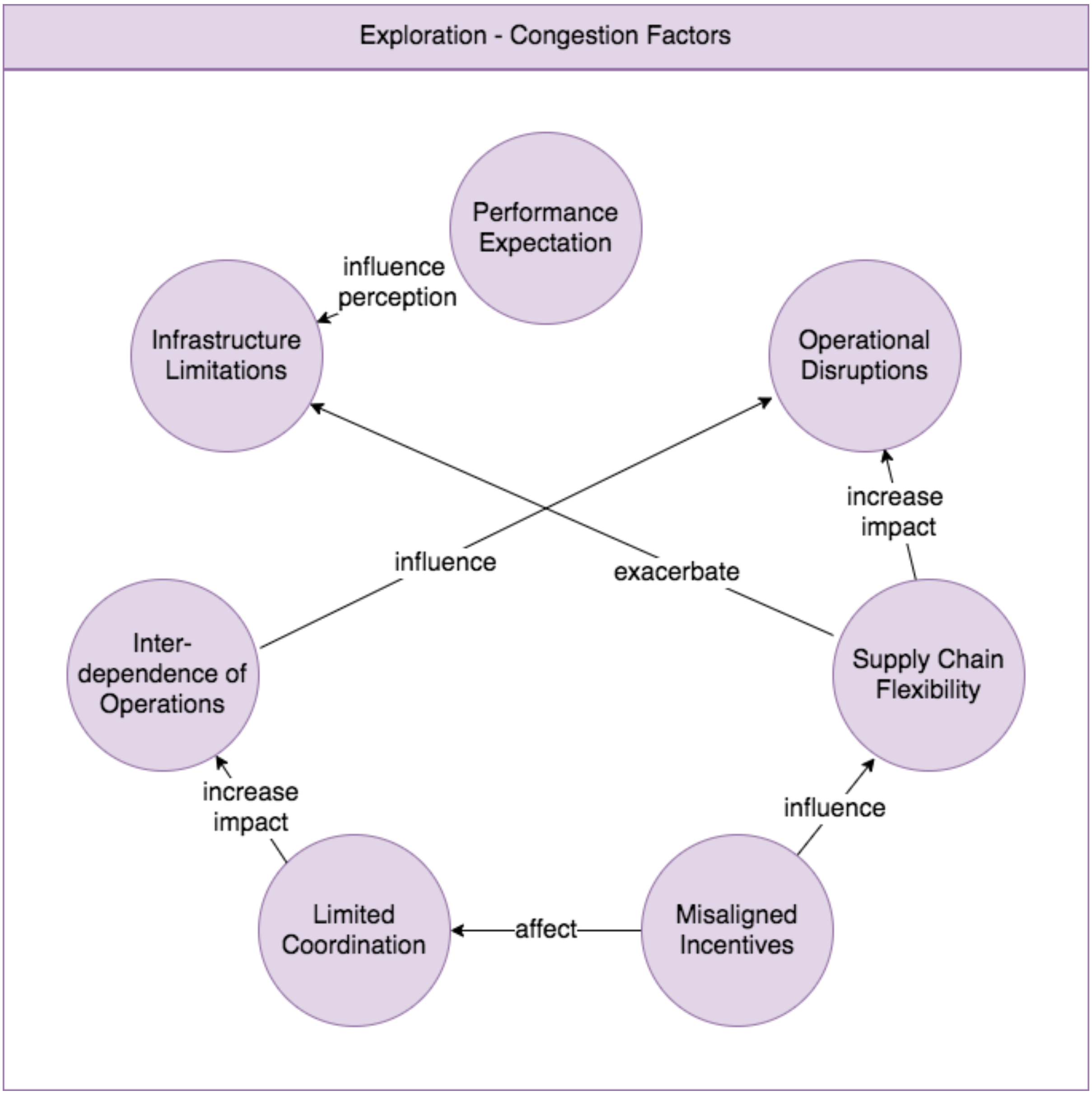


Figure 33 Stage 1: Exploration - Congestion Factors Axial Codes

Figure 33 illustrates the axial codes and their relationships emerging during Stage 1: Exploration within the CONGESTION FACTORS core category. The axial codes in this core category are discussed next and exemplified with excerpts from interviews.

5.2.1.1.1 Infrastructure Limitations

Terminal infrastructure limitations was considered as one of the primary factors conducive to the appearance of congestion by most of the participants.

> **Bobby (Haulage Operator/Case A):** "*The biggest thing for this operation would be more tipping ramps or quicker unloading facilities so we can unload and go get the drivers in their rhythm of going round and round, not getting bored and frustrated with hold-ups.*"

Bobby's account is particularly illustrative of the perceptions echoed by participants across the 3 cases. His account raises in fact 2 issues with the terminal infrastructure: insufficient unloading infrastructure as well as slower-than-expected unloading speed. The slower-than-expected unloading speed was a recurrent aspect of infrastructure limitations across the three cases. Participants in Case A also mentioned the congestion at the weigh-bridge facility, partially because it was shared with other port users, and partially because, a single weigh-bridge served both inbound and outbound terminal flows. Several participants in Case C also highlighted that the terminal layout, which was compressed due to space restrictions, forced trucks to drive additional distances and also contributed to congestion. In Cases A and C, several terminal operator staff also recognised several infrastructure limitations. However, within the same organisation there were cases of disagreement regarding the limitations of the terminal infrastructure.

> **Brian (Terminal Operator/Case C):** "*If you do X million tons a year through this facility that number is achievable. If you do Y (Y>X), that number is not achievable. Because the ramps are designed to do half a million tons each. So, we're trying to put Y into something that's designed to do X.*"

It is important to note that the discussions in Case C took place during a time when one of the 3 unloading ramps was not operational. Many respondents suggested that the breakdown had had a somewhat negative effect on their truck turnaround times, contributing to the congestion.

INFRASTRUCTURE LIMITATIONS were influenced by *SUPPLY CHAIN INFLEXIBILITY* and *PERFORMANCE EXPECTATIONS.*

5.2.1.1.2 Interdependence of Operations

The **interdependence** between organisations in the supply chain was recognised by most participants across the three cases. Interdependence was primarily recognised within the context of supply chains in which individual organisations were involved in. This is illustrated by Garry's story:

> **Garry (Wood Chip Processor/Case A):** [Interviewer: If the vessel arrival time changes, let's say it goes out 10 days, how does that impact your plan?] "*Well it impacts the deliveries and impacts the drivers because I'd have to reforecast the daily average. But that's not really ideal for our business because then we have to play onto the next product.* […] *it's critical that our shipping team deliver on what they say the vessels are coming and stick within the laycan which is about 10 days. It's critical to our business.*"

Thus, in the context of an individual supply chain, changes in the shipping schedules can affect the transportation schedules and ultimately their frequency of arrival at the terminal. However, it is important to note here that this interdependence was primarily recognised in the context of the participant's organisation and supply chain but not necessarily in the context of other port users.

Site visits undertaken in Case C also revealed that in-field wood chip production was influenced by the availability of trucks. During one of the site visits, the woodchip operator were unable to work because the trucks had not arrived in the forest coupe. Subsequently, several trucks arrived. Informal discussions with the production supervisor revealed that it was highly likely that the trucks that had just arrived in the forest coupe would also arrive in close sequence at the terminal.

INTERDEPENDENCE OF OPERATIONS was influenced by the level of *SUPPLY CHAIN COORDINATION*. The terminals in each of the cases served as intersection points for multiple supply chains, or for a multiple material flows that operated relatively independently. This vantage point provided terminal operators' staff with a perspective on the interdependence between operations of multiple material flows and supply chains:

> **Alex (Terminal Operator/Case A):** "*I can pre-empt that* X *are going to campaign a product* [high frequency deliveries] *after their next vessel so that's gonna ultimately keep* Y's *trucks out. It's not gonna affect* [the terminal's] *business, because even though* X *have an increase in product,* Y *will see in their daily deliveries drop, but the facility will probably see an increase in tonnage."*

The decisions of one forestry company to temporarily increase production and consequently the number of trucks arriving at the terminal on a daily basis were expected to impact the operations of another. These independent decisions taken by an individual company had an effect on operational clashes with other terminal users and subsequently on the level of congestion experienced at the terminal.

5.2.1.1.3 Operational Disruptions

Operational disruptions were also perceived as a congestion factor by a large proportion of respondents. Disruptions could be caused by adverse weather events, contamination of wood chips or capacity limitations in the supply chain. Across the three cases, operational disruptions were often discussed, however, the type of operational disruption considered most relevant was different. In Case A, as Bobby's story highlights, adverse weather would cause delivery suspensions at the terminal. Operational disruptions due to weather would often facilitate the appearance of congestion after deliveries at the terminal are resumed, as most trucks would be full and ready to unload.

> **Bobby (Haulage Operator/Case A):** *"When there's easterly wind and they stop us tipping there's a list that* [the terminal operator] *notify. So, they'll notify me. Quite often it's in the middle of the night. So, I'll get out of bed and send a group text message to all the drives. 'Port closed, stand by at the depot'. Empty trucks I want them to go and put a preload on, they might go back and preload and come back here. If I need empty trucks for the bush or think I might go to send extra trucks the bush the next day to help the bush operator out. Because if the port looks like it's gotta be closed for a few hours, this first lot of trucks will get loaded and if they can't tip off then he can't work. What we do, I'll send them to the bush so at least he can chip 14 loads. When the port opens, we can tip them off and then go back to the mill."*

The impact of *OPERATIONAL DISRUPTIONS* was influenced by the level of *SUPPLY CHAIN FLEXIBILITY*. Bobby's account also highlights that when multiple options are available, trucks can be sent out to different forest coupes, especially those located furthest away. Conversely, the limited flexibility of trucks in terms of unloading mechanisms can facilitate the appearance of congestion. Informal discussions with other participants revealed that, if it was likely the terminal will resume unloading within a reasonable amount of time, some of the contractors would queue up their trucks at the terminal to be the first to unload.

OPERATIONAL DISRUPTIONS were influenced by *INTERDEPENDENCE OF OPERATIONS*. Thus, behaviours of other parties in the supply chain had an effect on the appearance of operational disruptions. In Case C, the leading causes of operational disruptions was product contamination or sub-standard quality. Product contamination occurred when materials other than wood chips are delivered at the terminal. Any materials that may be unloaded from trucks have to be removed immediately, prior them reaching the stockpile. When contamination events happen, terminal deliveries are suspended. Trucks however can continue to arrive and wait for the issue to be resolved. It is not always possible to estimate the duration of delivery suspensions. As a result, trucks often end up waiting at the terminal for unloading to be resumed.

> **Christine (Chip & Transport/Case C):** Contamination at the terminal slows down the deliveries
> - excerpt from interview notes -

Importantly, the sub-standard product quality would also cause operational disruptions. This occurred primarily in Case C, due to their operational setup (a re-chipper at the terminal to process sub-standard products – see Figure 22, p.79). Brian's story illustrates how sub-standard products can cause a slow-down of deliveries and facilitate the appearance of congestion.

> **Brian (Terminal Operator/Case C):** "*I only look at the chip quality data, that's the most important. Because if the chip comes in and it's in spec the system just runs smoothly. If you get a load of oversized chip the system can do one or two things: it slows down or the system shuts down until that load is processed through the re-chipper. As an example, if I deliver a load of out of spec chip, it goes in the bin, my truck comes down order, I drive off and I'm gone, the guy behind me is penalised because he has to wait until that load is processed.*"

It is likely that individual sub-standard deliveries would have a cumulative effect on trucks already waiting at the terminal and that a series of sub-standard deliveries would cause significant operational disruptions at the terminal.

5.2.1.1.4 Limited Coordination

The limited coordination emerged on three levels: individual organisations, between organisations in different material flows or supply chains, and along the supply chain.

<u>Individual organisations</u> encountered challenges coordinating their internal operations and end up causing their own issues, as Garry's account illustrates:

> **Garry (Wood Chip Processor & Transporter/Case A):** "*If I gotta campaign* [high frequency truck deliveries at the terminal] *and put 7 or 8 on the run, you know get contractors in, it's not viable. Cuz sometimes you find that you're creating your own waiting times. Because I got drivers, you know, you might have 3 waiting in line for one to load and then it becomes a wait time. So, I find that 5-6 trucks running here, I can't do anymore, because if I do, I'm creating my own issues.*"

The relatively compact transport route between the wood chip processing site and the terminal meant that only a limited number of trucks could be added on the route until the trucks would wait for one-another. Truck queuing would most often occur either at the loading site or at the terminal where the trucks unloaded. Some participants, particularly amongst transporters, appeared more aware and explicit than others about internal coordination issues

The <u>limited coordination within supply chains</u> was often observed by the terminal operators due to their vantage point. Alex's account highlights that congestion events frequently occurred at known hours.

> **Alex (Terminal Operator/Case A):** *"Probably 6am, 11am, 4pm, there might be a bunch of trucks coming in."*

Informal discussions with the transporters in Case A revealed that they would control the starting times of their trucks in the morning but provide limited guidance to truck operators during the day. Consequently, the transporters' operations would end up overlapping and cause delays.

Importantly, Alex's account also illustrates the <u>limited coordination across the supply chain</u> and how *SUPPLY CHAIN COORDINATION* was affected by *MISALIGNED INCENTIVES*. Throughout the discussions with stakeholders, across the three cases, the times of day in which trucks would arrive were relatively well known. However, coordination efforts along the supply chain were rare. This situation was facilitated by the misalignment of inceptives along and across the supply chains. Thus, from the terminal operator's perspective, the parties that should be involved belonged to the different supply chains that intersected at the terminal: **Alex (Terminal Operator/Case A)** *"They* [the transporters & forestry companies] *need to start communicating between themselves."*. However, respondents from other organisations suggested that the terminal operator should be the one tasked with coordinating all the parties together: **Danny (Forestry Company/Case A)** *"In the absence of having everyone together,* [the terminal operator] *are the only ones that hold all the information"*.

The limited coordination was also highlighted in vessel arrivals and schedules, which were much more frequently discussed by participants across the three cases. In Case A, where two competing forestry companies were independently scheduling their vessels, leading to operational clashes, this issue was most pronounced because it also led to demurrage payments for vessel waiting time. Nonetheless, although these events would occur with relative frequency, there was limited evidence of coordination between organisations or along the supply chain.

5.2.1.1.5 Incentive Misalignment

The **misalignment of incentives** between various parties contributed to the appearance of congestion. Incentive misalignment can occur when individual players make decisions considering local rewards or objectives which differ from decisions that can maximise overall profitability (Simatupang and Sridharan, 2002).

The forestry companies in all cases scheduled vessel arrivals independently and therefore, once vessel owners or shipping agents are informed of another, potentially conflicting, vessel arrival, they would attempt to speed up to arrive first at the terminal. This behaviour led to vessel waiting times, which incurred costs for forestry companies, as well as truck congestion, since trucks are required to constantly deliver to ensure product availability. The impact of this behaviour was described in Section 5.2.1.1.2, p.113. This competitive behaviour is summarised by Alex:

> **Alex (Terminal Operator/Case A):** *"Sometimes they'll race. The customers will race each other to get here first.*"

MISALIGNED INCENTIVES influenced the *SUPPLY CHAIN INFLEXIBILITY*. Similarly, on the landside side, to fulfil contractual obligations, the forestry companies would request wood chip deliveries to the terminal even when aware of the potential implications this might have in terms of congestion:

> **Charles (Forestry Company/Case A):** *"The trucking is difficult to communicate when we have both conflicting objectives. We* [forestry companies' representatives] *would talk openly, he'd tell me he's short 10,000 tons and he needs to get them there, and I'd equally say I'm full with wood chips and I need to get them to the port."*

Incentives could be misaligned between organisations operating in the same supply chain, but also between organisations operating in different, potentially competing supply chains.

5.2.1.1.6 Supply Chain Flexibility

The level of supply chain flexibility was considered a factor for congestion by many participants, primarily in Cases B and C where production and deliveries were not restricted to a limited number of sites. Flexibility could help relieve congestion whilst inflexibility could exacerbate its appearance, as highlighted in Beatrice's account:

> **Beatrice (Wood Chip Processor & Terminal Operator/Case B):** "*So if we have too much log here, we can move some of that resource at* [another terminal], *to relieve some congestion here. We don't have the same luxury with* X *supply because we have a supply agreement for* Y *million tons. It's imperative we try to meet that almost at the cost of our own wood supply.*"

On the timber production side, the majority of chipping and transport operators in Cases B and C revealed that the changes in production site distances from the terminal could affect the level of congestion, as shown in the interview notes below.

> **Eric (Chipping and Transport Operator/Case C):** harvesting planning should be improved to mix long and short distance coupes;
> **Fred (Transport Operator/Case C):** mixture between coupes scheduled at long and short distances
> **Christine (Chipping and Transport Operator/Case C):** diversify harvest planning in different areas (summer/winter coupes)
> - excerpts from interview notes -

Higher distances between production sites and the terminal would allow for the trucking fleet to disperse and arrive at different intervals, while smaller distances would often lead to clustered truck arrivals. Some operators were taking measures, where possible, to send trucks in furthest production sites to limit waiting times at the terminal and potentially relieve congestion.

5.2.1.1.7 Performance Expectations

A limited number of participants in Cases A and C expressed the performance expectations with regards to the terminal and average truck turnaround times. These performance expectations, in both cases, appeared driven by contractual terms. Charles' account is illustrative of the way performance expectations were constructed in their organisation's case.

> **Charles (Forestry Company/Case A):** "*When we started operations in the* [terminal], [the transport operator] *did the stopwatch measurement of the tipping ramp of the port and submitted his tender, along with others, he'd based his cost around a nominal turnaround time of 17 minutes, that's where that 17 minutes came from. It wasn't that they were doing 17 minutes at that time.*"

It is interesting to observe that the stopwatch measurement by the transport operator was factored in as an average in the costings. However, it was not clear whether there were allowances made for the variation of the average or whether the average was considered *in-lieu* of the maximum.

PERFORMANCE EXPECTATIONS influenced the perception of *INFRASTRCTURE LIMITATIONS*. Truck turnaround times were also perceived to be affected by throughput levels in comparison to the capacity of the terminal's infrastructure. Brian's account highlights the 45-minute threshold in terms of truck turnaround times:

> **Brian (Terminal Operator/Case C):** "*There is a set time, I think it's 45 minutes for trucks we're meant to offer. We will never get to that point, even when the third ramp's running. we will never get to the point. Because you can only put a litre of water in a litre bottle.*"

It was unclear whether the 45-minutes represented the average or the maximum threshold, however, the 45-minutes appeared to be the standard with which the performance of the facility was compared with.

A key observation emerging from the discussions on performance expectations between the two cases is the stark difference in truck turnaround times mentioned in the cases. In Case A, the performance expectation is 17-minutes, while in Case C, the expectation was for a 45-minute truck turnaround time.

The next section explores the core category CONGESTION IMPACTS AND CONSEQUENCES.

5.2.1.2 Congestion Impacts and Consequences

The CONGESTION IMPACTS AND CONSEQUENCES core category refers to aspects of congestion that had an influence on individuals, organisations or the supply chain as a whole.

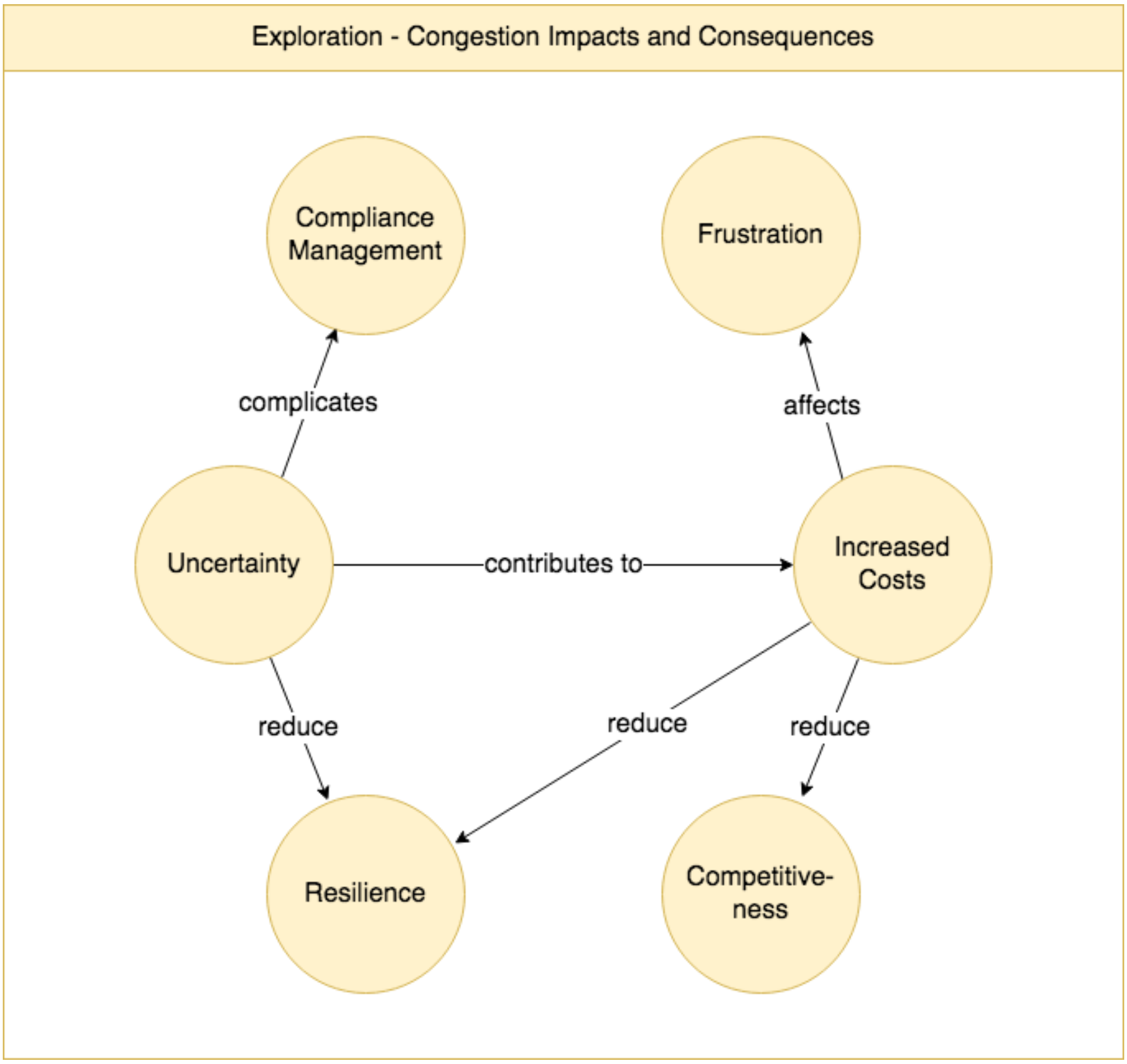


Figure 34 Stage 1: Exploration - Congestion Impacts Axial Codes

Figure 34 illustrates the axial codes and their relationships emerging during Stage 1: Exploration within the CONGESTION IMPACTS AND CONSEQUENCES core category. There were five axial codes associated with this core category:

- *INCREASED COSTS* refer to additional operating expenses born by stakeholders that are directly or indirectly linked to truck congestion at marine terminals.
- *FRUSTRATION* describes feelings of anger or annoyance expressed or inferred by the researcher in response to congestion or behaviours of participants in the supply chain.

- *UNCERTAINTY* refers to the unpredictable variability of truck turnaround times and throughput.
- *COMPLIANCE MANAGEMENT* refers to the ease with which truck operators, organisations and the supply chain as a whole can adjust their behaviours to adhere to regulatory frameworks.
- *COMPETITIVENESS* refers to the ability of organisations and the supply chain to maintain an economically viable price and cost structure in relation to other similar organisations or supply chains.
- *RESILIENCE* refers to the ability of the supply chain and operations to resist, absorb and recover from disturbances.

The axial codes in this core category are discussed next and exemplified with excerpts from interviews.

5.2.1.2.1 Increased Costs

The majority of the participants, particularly those engaged in transportation activities mentioned increased costs as a main consequence of congestion.

> **Gabriel (Chipping and Haulage/ Case C):** Saturday work for drivers to pick up remaining deliveries.
> - excerpt from interview notes -
> **Booby (Transporter/Case A):** *"They've* [the terminal operator] *got a constant supply of trucks coming in, but for us* [transporters], *while we're sitting out the back, we're burning money, our own money. Because we have to shift tons to make money."*

Gabriel's and Bobby's accounts illustrate the ways in which congestion can lead to increased costs for their business: The waiting time at the terminal is generally not remunerated by the transporters' customers nor the terminal operator. As a result, fuel, labour and maintenance expenses accrued during waiting are equivalent to "*burning money*". Bobby also highlights the differences in perspectives between the terminal operator and transporters in that the terminal may not be as affected by congestion and therefore not fully understand its implications. In informal discussion, a forestry company representative briefly touched on the limited short-term cost implications of congestion on their business due the existing contractual arrangements but acknowledged the possibility that the increased costs due to congestion could eventually lead to increased transportation costs in the future.

5.2.1.2.2 Frustration

Frustration also emerged frequently as a congestion consequence. Frustration was most often directly expressed in Case A but also surfaced in the other cases as well. Charles' account highlights the frustration he was experiencing:

> **Charles (Forestry Company/Case A):** "*Let's stop weighing twice, so that fuel, that labour, that wear and tear. why are we doing that? That's frustrating. We shouldn't be talking about that. Having actions and plans, people on the ground will say this is ridiculous stop doing this.*"

It was also apparent from Charles' story that frustration arose with repeated occurrences of congestion and with the perception of insufficient action taken to alleviate congestion.

The interviews for Case C were undertaken during a time when the terminal had suffered a severe breakdown that affected its truck unloading capacity. The researcher was warned by the terminal operator in Case C that some degree of frustration may be expressed by chipping and haulage contractors.

5.2.1.2.3 Uncertainty

Uncertainty emerged during the discussions with several participants. Uncertainty was particularly evident in Case B. Carter's account from interview notes is illustrative of the uncertainty their business was experiencing:

> **Carter (Harvest and Haulage/ Case B):** you don't get there early you're stuffed
> - excerpt from interview notes -

In Case B, the terminal opened for deliveries at 6am, however many trucks arrive at the terminal earlier than this time (see Section 5.3.1.4). This situation was largely created by the perception that the terminal would have insufficient capacity to process all trucks that would arrive in the morning. However, this perception of uncertainty of truck processing reinforced the pattern of uncertainty of truck turnaround times, as the number of trucks that arrived prior to the terminal opening times increased and as their arrival time was earlier and earlier.

UNCERTAINTY contributed to INCREASED COSTS. The pattern of trucks arriving earlier than the terminal opening times was also contributing to increased costs as the cost of the truck operators' waiting time was typically born by the transporters.

5.2.1.2.4 Compliance Management

Challenges in managing compliance also emerged as a result of congestion. Compliance management was especially emphasised in Cases B and C where driver fatigue management was strictly monitored and enforced under the *Chain of Responsibility* regulatory framework (see Section 2.3.2.2). David's excerpt during the interview highlights this challenge:

> **David (Chipping and Haulage/ Case C):** there is a cost of lining up trucks and a higher risk of fatigue compliance breaches
> - excerpt from interview notes -

COMPLIANCE MANAGEMENT challenges were increased by UNCERTAINTY. The uncertainty of truck turnaround times meant that transporters would have difficulties to evaluate whether truck operators had sufficient time, under the nationally prescribed guidelines, to complete an unloading cycle and return to the depot or home.

> **Brian (Terminal Operator/Case C):** "*Contractors do communicate, juggle, because we had trucks left on site because the drivers were out of time because they can't continue driving.*"

In cases where truck operators were unable to complete unloading, replacement operators were required as Brian's account shows.

5.2.1.2.5 Competitiveness

The competitiveness of the supply chain could also be affected by congestion. This was primarily recognised by representatives of the organisations that had a broader view of their supply chain, such as forestry companies or vertically integrated terminal operators. In severe congestion cases, the ability of forestry companies to aggregate sufficient product on the terminal to fulfil sales can be impaired, as Anthony's account illustrates:

> **Anthony (Terminal Operator/Case C):** [Researcher: What happens if you're not cargo ready?] "*So, if we can't fulfil our obligations, they* [the customers] *may go somewhere else because they know you can provide us wood chip but not all the time. Because they plan their whole production based on when those vessels arrive so if we are unreliable it means that their vessels aren't utilised as best they could and also their supply of woodchip would be unpredictable. So, there is a very large implication.*"

Although the situation Anthony described was only hypothetical, it highlights the significance of competitiveness for the supply chain. Competitiveness becomes a critical aspect given that wood chip supply chains generally serve a limited number of customers, as Elliott describes:

> **Elliott (Forestry Company/Case A):** *"There's ultimately so many customers* […] *ultimately only maybe 20-30 consumers of industrial quantities of wood chips in the Asia-Pacific region. Everyone is chasing them and they're chasing a certain amount of volume."*

It is evident that, forestry companies would be the first affected by the lack of competitiveness. However, the implications of such a situation would be rapidly felt by other stakeholders in the supply chain.

5.2.1.2.6 Resilience

The implications of congestion on resilience emerged in Cases A and C. Similarly, to competitiveness (Section 5.2.1.2.5), resilience implications were primarily recognised by representatives of the organisations that had a broader view of their supply chain, such as forestry companies or vertically integrated terminal operators. Resilience implications largely stem from the UNCERTAINTY and INCREASED COSTS. Anthony's account highlights the resilience implications of congestion:

> **Anthony (Terminal Operator/Case C):** "*Over there is a very large risk with contractors because their ability to absorb* [losses]. *So, let's say we're shut down because of the damage caused to the plant or we didn't maintain it for two weeks all these guys would have serious financial difficulties because of their payments. It's a volume there it's about getting as much volume in as possible though getting so much for time if they're not getting enough volume that is how they make the money. So, by our inability to receive the chip has implications on their business. because they're setting the contracts up and their pay rate on how many tons, they think they're gonna produce. And it by our actions for*

> *maintenance or other reasons they cannot deliver that means financially they could go bust.*"

Thus, the ability of contractors to weather the natural ebbs and flows of the global wood chip demand may be impaired by decreased revenues, especially when this occurs over a lengthy period of time. The increased bankruptcy risk for chipping and haulage contractors could translate to insufficient adaptive capacity for the forestry companies to deliver the required products and thus compete on the international market.

The next section explores the core category THE ROLE OF INFORMATION SYSTEMS.

5.2.1.3 Role of Information Systems

The ROLE OF INFORMATION SYSTEMS core category refers to aspects pertaining to information technology and information sharing in organisations and across the supply chain.

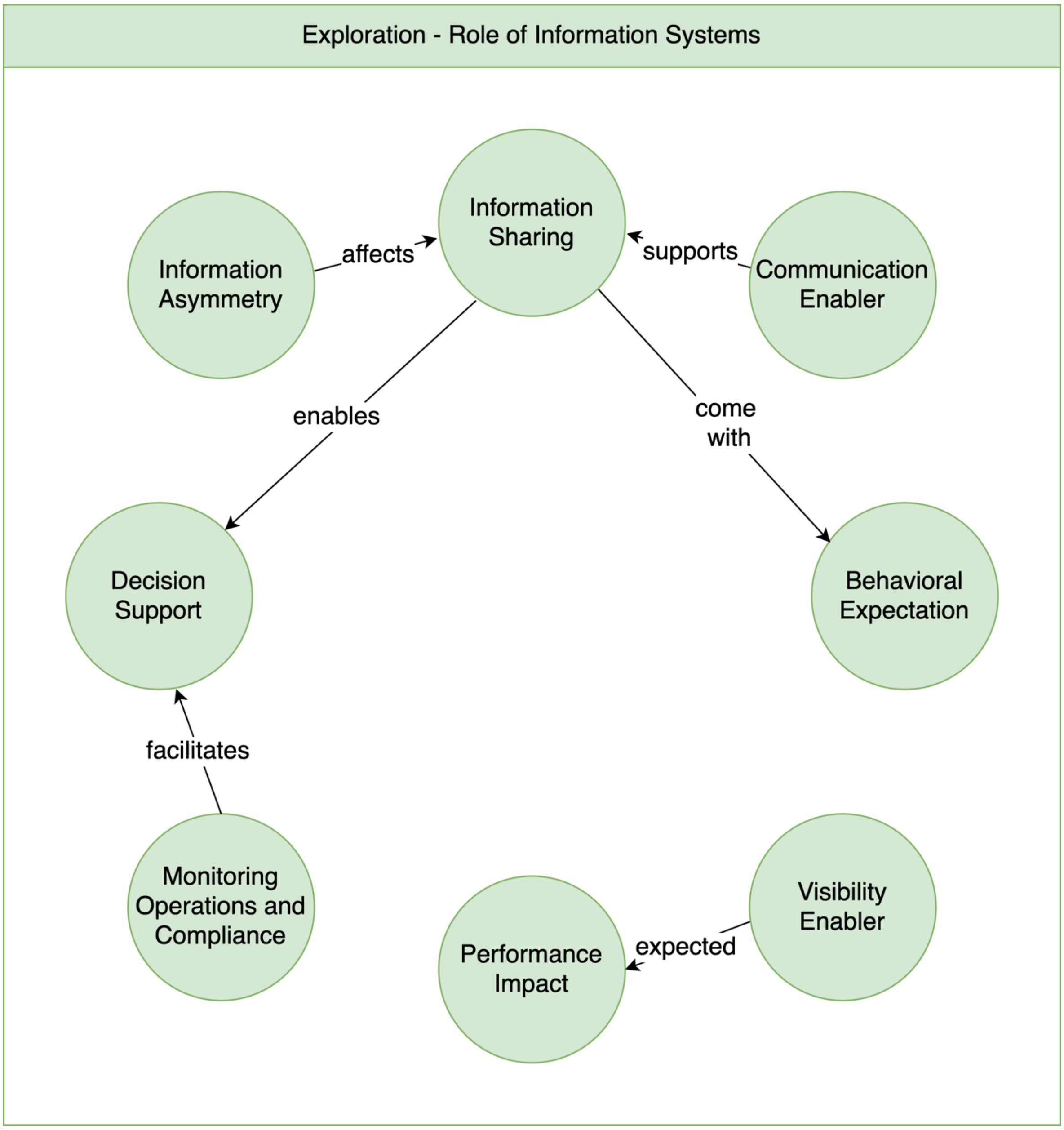


Figure 35 Stage 1: Exploration - Role of Information Systems Axial Codes

Figure 35 illustrates the axial codes and their relationships emerging during Stage 1: Exploration within the ROLE OF INFORMATION SYSTEMS core category.

There were eight axial codes associated with this core category:

- *MONITORING OPERATIONS AND COMPLIANCE* refers to the use of information systems to track progress against expectations or plans and to verify the extent to which policies and regulations are being followed.
- *COMMUNICATION ENABLER* refers to the role of information systems in reducing or eliminating geographical proximity and synchronicity requirements for communication.
- *INFORMATION SHARING* refers to the human activity of, formally or informally, requesting or releasing information to stakeholders belonging to other organisations.
- *DECISION SUPPORT* refers to information or tools that contribute to and influence the decision-making process of stakeholders.
- *INFORMATION ASYMMETRY* refers to the differences in availability of information between participants.
- *VISIBILITY ENABLER* refers to the generation or collection of previously unavailable data on different aspects of supply chain operations, using technology tools.
- *BEHAVIOURAL EXPECTATIONS* refer to the belief stakeholders have regarding the use others make of the data made available or information shared.
- *PERFORMANCE GAINS* refer to the cost, efficiency or effectiveness impact of information systems.

The axial codes in this core category are discussed next and exemplified with excerpts from interviews.

5.2.1.3.1 Monitoring Operations and Compliance

One of the most frequently mentioned roles of information systems was for **monitoring operations and compliance**. This axial code emerged in all three cases and from a large proportion of participants. Beatrice's account provides an illustration of monitoring operations and compliance:

> **Beatrice (Terminal Operator/Case B):** "*The system we use for daily deliveries is the NaVision system. I just run a daily report. Sometimes hourly. We have a spreadsheet where it all gets plugged into. It aligns our intake, how much wood we chip, how much* [the contractors] *cart, how much chip we have at the port. And all of those align to create a flow throughout the year.*"

Often, monitoring operations and compliance was accomplished using digital tools such as databases, excel spreadsheets or wood flow management systems. The vast majority of transport or haulage contractors used some sort of geo-positioning system on their trucks to track their whereabouts.

MONITORING OPERATIONS AND COMPLIANCE facilitated *DECISION SUPPORT*. This is illustrated in Anthony's account on the use of the wood flow database:

> **Anthony (Terminal Operator/Case C): "***We have a wood flows database that combines the delivery data and projections of volumes for the year and it also has the estimated time of arrival or place holder for vessels that are planned to come to keep an eye on the inventory levels and identify if there is a need to push vessels out because we want the current already order to slow deliveries down because will be full. So, recently had to stop softwood deliveries because our stockpile was full but it's constantly monitoring the data. Wood chip in wood chip out."*

Thus, changes in the operational numbers would trigger, in some cases, discussions or decisions to change vessel arrivals due to the perceived inability to fulfil orders based on existing flows. In the vast majority of cases, the decisions supported through monitoring and compliance were primarily reactive and operational. Such decisions often related to reaching or managing infrastructure or capacity bottlenecks.

5.2.1.3.2 Communication Enabler

Communication enabler was a role also frequently mentioned by large proportion participants in all three cases. This axial code emerged particularly in relation to tools such as the mobile phone or email applications. Brian's account is illustrative of the importance of the mobile phone for accomplishing his daily tasks:

> **Brian (Terminal Operator/Case C):** [Interviewer: But the most important thing is having a telephone] "*It is, you can send emails, text messages, you can ring people.*"

Brian's account illustrates the importance placed on asynchronous and synchronous communication capabilities offered by the mobile phone.

COMMUNICATIONS ENABLER supported *INFORMATION SHARING*. The mobile phone in particular was used to facilitate information sharing between participants belonging to different organisations, as Bobby's account illustrates:

> **Bobby (Transporter/Case A):** "*Generally, it's X, he quite often rings me in the late afternoon. Most days when he's leaving the mill.*"

Depending on the type of activity the participants were undertaking, the mobile phone or email would be mentioned more frequently. In operational roles, the mobile phone appeared to be considered more important. In managerial and clerical roles, the participants mentioned the use of emails more often.

5.2.1.3.3 Information Sharing

Information sharing emerged during the coding process. Information sharing was a frequent occurrence amongst the majority of participants. Information sharing often emerged in relation to individual responsibilities or organisational objectives. Thus, participants required information from others within or outside their organisation to fulfil their individual tasks. This was observed across the three cases and participants in each case. Alex's account on information sharing on vessel arrivals is illustrative of the reasons for which he engages in information sharing:

> **Alex (Terminal Operator/Case A):** *"If I'm not getting the information out of the local source, I'll leapfrog to someone who can give me the answers. I need the answers because I need to build the rosters for the ship loading."*

In other cases, information sharing was initiated by some organisations in order to raise awareness in their partner organisations about issues beyond their partners' field of view that were however important for the supply chain.

Information sharing was most frequently between two participants, whether in regular meetings or informal settings. Whilst the idea of stakeholder meetings that involved multiple participants was frequently vehiculated, it did not appear to be a regular practice across the three cases.

INFORMATION SHARING was linked with *INFORMATION ASYMMETRY*. The awareness of the existence of information in partner organisations and the awareness whether information could be shared were important factors affecting the level of information sharing.

INFORMATION SHARING was also linked with *BEHAVIOURAL EXPECTATION*. Following information sharing some participants expressed the expectation that the receiver instantiates certain behaviours. A frequently mentioned behaviour expected by those sharing information was feedback (see Section 5.2.1.3.5).

5.2.1.3.4 Information Asymmetry

Information asymmetry emerged during the coding process. Information asymmetry was categorised along two key dimensions: understanding availability and information completeness. Information asymmetry issues arose primarily in Case A, with some occurrences in Case C.

Information was in some cases unavailable for sharing due to confidentiality concerns. It was unclear from the data whether such concerns were substantiated in legal documents. In other cases, information was available for sharing but was voluntarily or involuntarily withheld. Generally, information was voluntarily withheld when organisations which were ostensibly competing wanted to maintain some level of discretion on their operations. In other cases, information simply did not reach the intended receiver. Finally, in other cases, information was available and could be shared but the issue of awareness came into play. The organisation that was interested in obtaining information was expected to ask, "the right questions", as Charles' story illustrates:

> **Charles (Forestry Company/Case A):** "*We all provide* [the terminal operator] *with contractual information.* [The terminal operator] *has never once asked me for anything else. They never asked what's happening for something that may affect the port operations.*"

The lack of awareness of information available in partner organisations raised questions regarding the person or entity responsible for initiating information sharing.

Information completeness was the second dimension of information asymmetry. Thus, information, particularly on aspects of the business undertaken by multiple organisations, was partially available to each organisation. However, central entities, such as the terminal operator were generally viewed as the aggregators of such information, and the holders of the complete picture.

INFORMATION ASYMMETRY affected *INFORMATION SHARING*. Information asymmetry had a strong influence on the level of information sharing between participants.

5.2.1.3.5 Behavioural Expectation

Behavioural expectations were mentioned by participants, primarily in Cases A and C and were related to information sharing. Two, partially interrelated behavioural expectations were mentioned by participants: feedback and decision adjustment. Feedback was by far the most common expectation. Following information sharing, it was commonly expected that feedback was provided by the recipient. Danny's quote highlights this expectation:

> **Danny (Forestry Company/Case A):** *"It's about data capture, the data provision, communication mechanism, and feedback mechanisms* […] *It's about cross-boundary cross-organisation. Do we set up an environment where we are happy to share information because in the end, we all win because the supply chain becomes most efficient as it can be."*

In some cases, the feedback expectation was a confirmation of receival of the information. However, in other cases, the behavioural expectation was a decision adjustment. In light of newly available or shared information, the recipients of the information were expected to adjust their decision making. However, this expectation was expressed by the person sharing the information and it was unclear whether the receiver of the information was aware of this expectation.

5.2.1.3.6 Decision Support

Decision support was an axial category emerging during the coding process. It was often the case that participants made reactive decisions rather than pro-active decisions. Whilst, many companies worked on forecasts to support and guide their decision making, forecasts were not always accurate or reliable. Christine's and Henry's interview notes highlight this issue:

> **Christine (Chipping and Haulage/Case C):** General plan for harvesting received one year in advance without specific coupe location
> **Henry (Chipping and Haulage/Case C):** Useful to know 12 months out a schedule to plan the yearly quotas
> - excerpt from interview notes -

The chipping and haulage contractors would receive information regarding their next production assignments with relatively little advance warning. In Case C, most notably, many of the chipping and haulage contractors mentioned the inaccuracy of forecasts and their inadequacy for supporting decisions.

DECISION SUPPORT was enabled by *INFORMATION SHARING*. Information shared by other organisations, in the case above, by the forestry company, assisted chipping and haulage contractors in managing their own equipment and taking decisions on longer timeframes.

5.2.1.3.7 Visibility Enabler

The role of information systems as a visibility enabler emerged as an axial code. Visibility enabler was mentioned across the three cases, by several participants, primarily those in managerial roles. This role was primarily related to digital tools that facilitated improved visibility. One property of visibility related to the timeliness of data that was made available. A main focus of many participants discussing timeliness of data availability was real-time data. The second property of visibility related to its breadth. Thus, the importance of visibility over a larger portion of operations was highlighted by some participants.

> **Arthur (Terminal Operator/Case B): "***I think the right information, say for instance for a supplier of wood, is to have a self-service portal where they can go have a look into, they can have a look at what wood was harvested today, where did the wood go to, how much has gone over the weigh-bridge. If we were doing the harvesting, where are the crews. Just a bit of an overview for them and giving them a flavour of what's happening on their own land. For people that we supply or for people that are suppliers and customers on both ends, doing I think a good go to, and I'm on the word portal because that's one of the things we think we should be doing. Is like having the shipping schedule there available, 24/7, live update, live information as it happens.* […] *But that's really what we believe is the right information for people.*"

Digital tools were at the centre of visibility enabling. Self-service portals and dashboards were the most frequently discussed. Arthur's story on self-service portals is illustrative of the visibility enabler role of information systems.

5.2.1.3.8 Performance Improvement

Performance improvement also emerged as an axial code. This category emerged primarily in Case C and was mentioned by few participants. Performance improvement was expected primarily in relation to landside congestion management. Interestingly, performance improvements appeared almost exclusively in relation to digital tools that had not yet been implemented. Anthony's account is illustrative of this axial code:

> **Anthony (Terminal Operator/Case C): "***You could envision that if a truck driver could log onto or if they could be notified straight away this is the current turnaround time at PCT or if harvest companies had enough data that they could be able to utilise times with lower congestion. Some tool that good assistance were planned that the better, that would help a lot.*"

PERFORMANCE IMPROVEMENT was strongly related to *VISIBILITY ENABLER*. Interestingly, performance improvements were primarily discussed in relation to digital technology that enabled improved operational visibility.

The next section discusses the relationships between the core categories emerging in Stage 1: Exploration.

5.2.2 Relationships Between Core Categories

The CONGESTION FACTORS core category refers to aspects of terminal and supply chain operations that are conducive to the appearance of congestion. There were 7 axial codes associated with this core category: *INFRASTRUCTURE LIMITATIONS*, *INTERDEPENDENCE OF OPERATIONS*, *OPERATIONAL DISRUPTIONS*, *LIMITED COORDINATION*, MISALIGNED INCENTIVES, *SUPPLY CHAIN INFLEXIBILITY* and *PERFORMANCE EXPECTATIONS.*

The CONGESTION IMPACTS AND CONSEQUENCES core category refers to aspects of congestion that had an influence on individuals, organisations or the supply chain as a whole. There were 5 axial codes associated with this core category: *INCREASED COSTS*, *FRUSTRATION*, *UNCERTAINTY*, *COMPLIANCE MANAGEMENT*, *COMPETITIVENESS* and *RESILIENCE*.

The ROLE OF INFORMATION SYSTEMS core category refers to aspects pertaining to information technology and information sharing in organisations and across the supply chain. There were 9 axial codes associated with this core category: *MONITORING OPERATIONS AND COMPLIANCE*, *COMMUNICATION ENABLER, INFORMATION SHARING, INFORMATION ASYMMETRY, BEHAVIOURAL EXPECTATIONS*, *DECISION SUPPORT, VISIBILITY ENABLER,* and *PERFORMANCE IMPROVEMENT*.

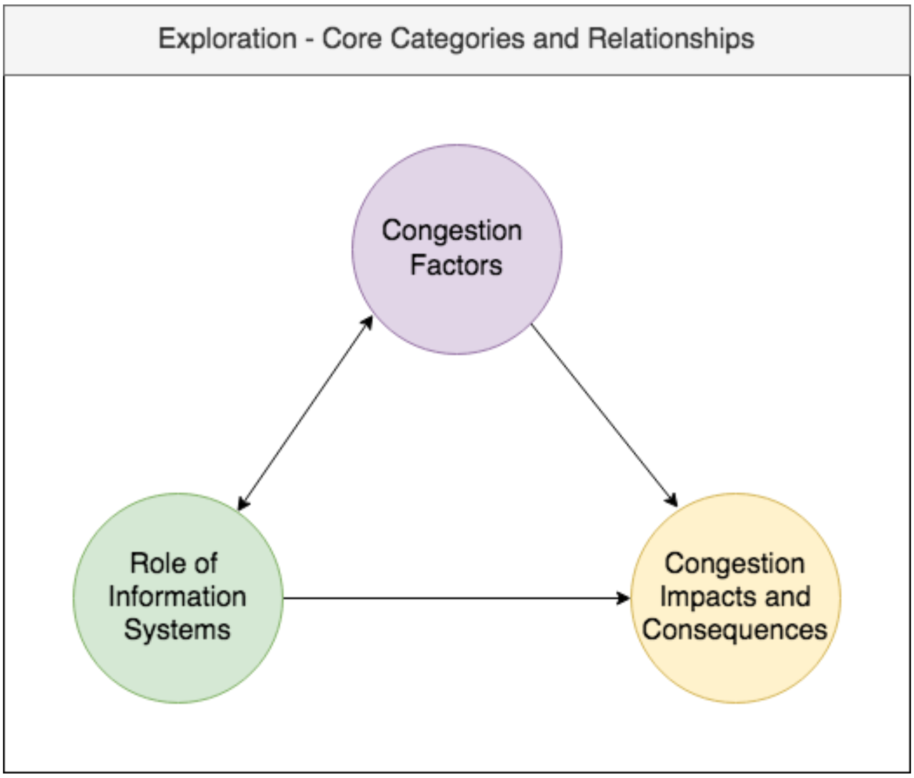


Figure 36 Stage 1: Exploration - Core Categories and Relationships

The relationships between the three core categories are illustrated in Figure 36.

CONGESTION FACTORS affected CONGESTION IMPACTS AND CONSEQUENCES. This was primarily due to *LIMITED COORDINATION*, *INTERDEPENDENCE OF*

OPERATIONS, *MISALIGNED INCENTIVES* and *SUPPLY CHAIN FLEXIBILITY* which influenced the extent of the congestion impacts and consequences. CONGESITON FACTORS also affected the ROLE OF INFORMATION SYSTEMS. This was mainly through *LIMITED COORDINATION*, *INTERDEPENDENCE OF OPERATIONS* which affected the need for communication, and improved operational visibility and control.

The ROLE OF INFORMATION SYSTEMS affected CONGESTION FACTORS. This was through *INFORMATION SHARING*, *COMMUNICATION ENABLER*, *VISIBILITY ENABLER* and *DECISION SUPPORT*. These aspects of information systems affected the extent to which congestion factors occurred in the operations. The ROLE OF INFORMATION SYSTEMS also affected CONGESTION IMPACTS AND CONSEQUENCES. This was primarily through *VISIBILITY ENABLER* and *DECISION SUPPORT*. These aspects influenced the uncertainty and compliance management challenges.

The next section presents the preliminary results emerging from Stage 1: Exploration.

5.2.3 Stage 1 Preliminary Results and Interpretation

The preliminary results obtained during Stage 1: Exploration through the iterative process explained in Section 4.7 helped guide the remainder of the analytical process. The preliminary results were:

ER-1. *The participants referred to congestion as a well understood and defined process but rarely expressed their expectations regarding acceptable congestion levels.* Performance expectations with respect to congestion were explicitly stated by two participants in Stage 1: Exploration, although these appeared to influence the perception of congestion for other participants (see Section 5.2.1.1.7). It was also unclear for the researcher whether when participants referred to the average truck turnaround time value, they meant in fact the maximum value. Consequently, the quantitative analysis aimed to understand the quantitative basis on which performance expectations were formed. Furthermore, this preliminary insight highlighted the need for a perspective alignment step in Stage 2: Design Workshops to develop a common vocabulary is developed amongst participants.

ER-2. *The factors conducive to the appearance of congestion were diverse and pretrained to the terminal and also the supply chain.* The congestion factors identified were:

(a) inadequate terminal infrastructure (Section 5.2.1.1.1);
(b) interdependence with other supply chain operations (Section 5.2.1.1.2);
(c) operational disruptions due to contamination, breakdowns, other port users and weather events (Section 5.2.1.1.3);
(d) limited coordination of logistics activities (Section 5.2.1.1.4);
(e) misaligned incentives (Section 5.2.1.1.5); and
(f) lack of operational flexibility (Section 5.2.1.1.6);

ER-3. *Inadequate terminal infrastructure appeared to be a symptom rather than a cause of congestion.* The factors mentioned most often by participants were inadequate terminal infrastructure and interdependence with other supply chain operations. It became apparent that inadequate terminal infrastructure was more likely a symptom of supply chain interdependency, limited coordination and operational flexibility rather than in itself an issue. In all three cases, the terminal infrastructure was sufficient to process the desired amount of wood chips in a given month or year. However, without quantitative evidence, the researcher suspected that stakeholders would persist in their beliefs that congestion was caused by insufficient infrastructure. Consequently, the exploratory data analysis in Stage 2: Design Workshops aimed to better understand whether and to what extent terminal infrastructure bottlenecks affected operations.

ER-4. *The way operations resumed after operational disruptions likely to facilitate the appearance of congestion*. Operational disruptions were issues mentioned across the three cases (Section 5.2.1.1.3). Some disruptions had common causes while others did not. A common cause of disruptions in all cases were vessel delays which reverberated within the supply chain. Other disruptions occurred for reasons that appeared to be specific for each case: in Case A, the majority of disruptions occurred due to weather events, in Case B, many appeared due to insufficient supply chain capacity, especially in the maritime and hinterland terminals and in Case C, many disruptions occurred due to poor wood chip quality. The disruption itself did not necessarily appear to be the cause of congestion. Rather, the way in which operations were resumed appeared to cause most issues. Following a disruption, most trucks would already be full and waiting to deliver cargo. Once the terminal would open, all trucks would head to the terminal to unload.

ER-5. *Many stakeholder behaviours appeared rational in light of individual incentives. However, from a supply chain perspective, these behaviours were contributing to congestion.* Many of the stakeholders' behaviours were in part related to the misalignment of incentives (Section 5.2.1.1.5). Stakeholders would behave in ways that was aligned with their own personal or organisational goals, most of the times at the detriment of other supply chain parties. This appeared especially true for stakeholders that were performing the same task even within the same supply chain, such as transporters, that often operated with conflicting objectives. Most transporters tried to maximise the daily, weekly or monthly wood chip deliveries at the terminal. However, in doing so, they most likely contributed to diminishing the possible supply chain maximum. An important part of the quantitative analysis was therefore aimed at highlighting the differences between different types of behaviours and their impact, not only on individual organisations but the supply chain as a whole.

ER-6. *The multitude and diversity of congestion factors also meant that there was significant heterogeneity in views between participants, potentially leading to disagreements on ways of mitigating congestion.* Even with respect to terminal infrastructure, there were differences in which part of terminal infrastructure was inadequate. This was particularly evident in Case A where there was disagreement whether the weigh-bridge, different capacity unloading ramps, or conveyor belt were responsible for the appearance of congestion. Similarly, multiple elements of the supply chain which operated interdependently were mentioned. The researcher suspected that this heterogeneity in perspectives across participants was likely to cause challenges in terms of mitigating congestion. Thus, if some participants believed that a congestion mitigation approach undertaken by another stakeholder was misaligned with the congestion factors they perceived relevant, they would be less likely to support those approaches. This preliminary insight strengthened the need to align perspectives of supply chain participants in order to proceed on common ground with participants.

ER-7. *Congestion had significant consequences on the individual firms and the supply chain as a whole.* The most frequently mentioned consequences of congestion related to costs (Section 5.2.1.2.1) and frustration (Section 5.2.1.2.2). However, implications for the competitiveness (Section 5.2.1.2.5) and resilience of the supply chain (Section 5.2.1.2.6) were also raised by some of the participants. While cost and frustration related to the individual firms, competitiveness and resilience were aspects that related to the supply chain as a whole. All organisations involved in the supply chain were likely to experience to some degree such consequences, directly or indirectly. Given that misaligned incentives and multiple perspectives were common between participants, competitiveness and resilience were considered useful sensitising lenses for developing a common vocabulary of the supply chain during stage2: design workshops.

ER-8. *It was suspected that the participants' convictions of the expected benefits of digital tools were not aligned with the use patterns of existing tools or grounded in a clear understanding of the mechanisms through which the benefits would be achieved***.** Most participants used information systems to monitor operations and compliance (Section 5.2.1.3.1) and to enable communication (Section 5.2.1.3.2). In some cases, the information generated by the systems used to monitor operations and compliance assisted participants with reporting or making decisions against set thresholds. However, several participants had an expectation that new digital tools could improve visibility on supply chain operations (Section 5.2.1.3.7) and therefore improve the performance of organisations and the supply chain (Section 5.2.1.3.8). This expectation was expressed by some but inferred by the researcher in other cases. The participants' expectations of performance improvement seemed disconnected from the way digital tools already installed were used as it was not clear which decisions were different compared to a situation where no digital tools were used. The researcher considered that there is a high likelihood that the performance expectations of the participants regarding new digital tools were set by external factors, such as technology vendors, more than from an understanding of the mechanisms through which technology would impact operations.

Information sharing was used extensively across the three cases (Section 5.2.1.3.3). Frequently, information sharing was initiated in relation to individual or organisational responsibilities. At the same time, information sharing seemed often occurring between companies that had some type contractual agreement. Participants in organisations that had no contractual agreements generally shared information informally. Two relevant aspects pertaining to information sharing emerged: information asymmetry and behavioural expectations.

ER-9. *Information asymmetry was likely a contributing factor impeding information sharing*. Often, participants believed that some information was confidential or could be used by their competitors to generate an advantage. It was unclear to the researcher whether these beliefs were founded on evidence or contractual terms.. Interestingly, it did not appear clear to participants what information was collected or available in their partners' organisations (see Section 5.2.1.3.4). The researcher suspected that these aspects relating to information asymmetry would be conducive to a situation where novel information sharing was less likely to occur. Based on this preliminary insight, during Stage 2: Design Workshops, the researcher emphasised the multiple sources of information available and encouraged the participants to discuss their information wants or needs.

ER-10. *Second, information sharing was often accompanied by expectations of behaviours from the recipients of the information.* One of the most basic expectation was that of providing feedback. Further, it was expected that the recipients of information act based on the information. In a few cases, this expectation was verbalised (see Section 5.2.1.3.5). The researcher suspected that a situation where the participants' expectations were not met by the recipients of information sharing would generate significant frustration and decrease willingness to engage in further information sharing. The researcher also suspected that the behavioural expectations following information sharing were not expressed often to the recipients of the information. This preliminary insight led to the development of the design workshop worksheets (illustrated in Appendix I) to help guide the design process.

The next section presents the analysis of the next stage of the participatory design approach, Stage 2: Design Workshops.

5.3 Stage 2: Design Workshops

The exploratory data analysis and simulation modelling used to support the workshops and the coding process drawing on the principles of grounded theory of the workshops data are discussed in this section. The quantitative data collected from weigh-bridge systems form all three cases and from truck geo-positioning systems in Case A were analysed using exploratory data analysis using the approach described in Section 4.6.2.2. These data also formed the input for the discrete-event simulation model inspired by the terminal in Case A. The development of the model was described in Section 4.6.2.1. The qualitative data collected from four workshops across the three case studies were analysed using the open, axial, and selective coding process described in Section 4.6.2.3. Data originating from the three cases was first open coded. Subsequently, all codes were systematically revised through constant comparison which led to the emergence of the axial codes. Selective coding to identify the core categories was employed guided by the research questions and objectives.

The exploratory data analysis results are discussed first. The simulation model scenario analysis results are discussed next. The 3 preliminary core categories emerging from the coding process drawing on the principles of grounded theory of the qualitative workshops are then presented. Finally, the insights gained during this research stage are discussed.

5.3.1 Exploratory Data Analysis

The exploratory data analysis procedures utilised are described in detail in Section 4.3.3.2.2. Visualisation and statistical summarisation techniques have been employed in this section to explore and better understand the process length for terminal infrastructure, truck turnaround times and arrival frequency.

5.3.1.1 Terminal Infrastructure Times

One of the congestion factors mentioned during Stage 1: Exploration was the terminal infrastructure (see Section 5.2.1.1.1). In Case A, truck geo-positioning data recorded the duration of trucks' visits on the terminal infrastructure was recorded. Truck geo-positioning data was not available in Cases B and C. It is however likely that, given the similarities between the terminal equipment in all cases, several insights revealed for Case A would be valid for Cases B and C. The geo-positioning data on the unloading ramp service time, entry and exit weigh-bridge duration were therefore visualised using histograms in Figure 37.

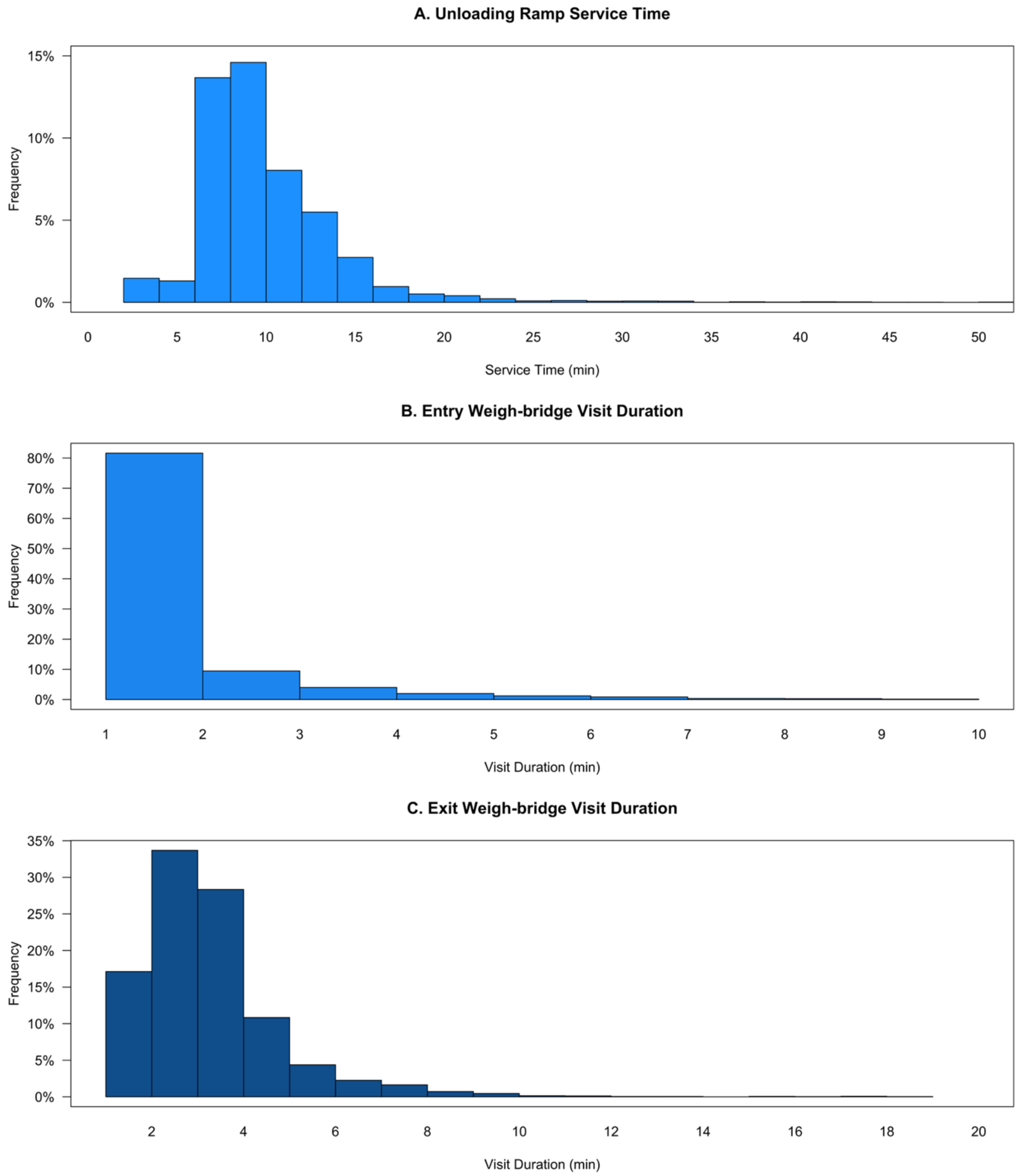


Figure 37 Case A - Unloading Ramp and Weigh-Bridges Service Times

Figure 37A shows the unloading ramp service time. The geo-fence covers the area where the unloading ramps are located. It was therefore expected that the measurements would indicate the time spent by a truck on the ramp and exclude any waiting time for the infrastructure to become available. Approximately 83% of service times lie within the 7- and 16-minute interval whilst 12% of the service times are lower than 7 minutes and the remaining 5% are higher than 16 minutes. The 7-minute lower boundary was considered following discussions with terminal staff and researcher' observation at the terminal. The geo-fence data can, at times, provide false readings, therefore segmenting a visit of a truck to a point of interest in multiple separate visits. Whilst the researcher cleaned the data for such occurrences (see data cleansing in Appendix

C), it is possible that some were not captured. However, visual inspection of the unloading ramp service times indicates relatively limited variability in the data.

Figure 37B and Figure 37C show the duration of the entry and exit weigh-bridge visits. The geo-fence setup for these visits includes a portion of road before and after the weigh-bridge equipment, therefore capturing much of the potential waiting times. However, the weigh-bridge visit durations show relatively little variation with more than 81% of entry visits under 2 minutes and 90% of the exit visits lasting less than 5 minutes. The difference between the two types of visits is that when exiting the terminal premise, the truck operators have to leave their trucks, take the weigh-bridge docket with the truck weight information, manually input some data and then return to their trucks. Whilst there are examples of longer visits recorded on both the entry and exit weigh-bridge visits, these appear to be isolated and relatively sporadic.

The truck turnaround time at the terminals in each case study data were investigated next.

5.3.1.2 Truck Turnaround Times

The inspection of truck turnaround times data revealed marked differences between the turnaround times average values as well as the distribution shapes. This preliminary insight contrasted with participants accounts in Stage 1: Exploration (Section 5.2.1.1) from all three cases that described congestion with similar words. It was therefore suspected that it was insufficient to study truck turnaround times in isolation from the performance expectations participants had.

Furthermore, the average truck turnaround time may misrepresent congestion. A large proportion of the truck turnaround times were in fact smaller than the average. However, the variability of truck turnaround times was generally large, and usually biased towards high values.

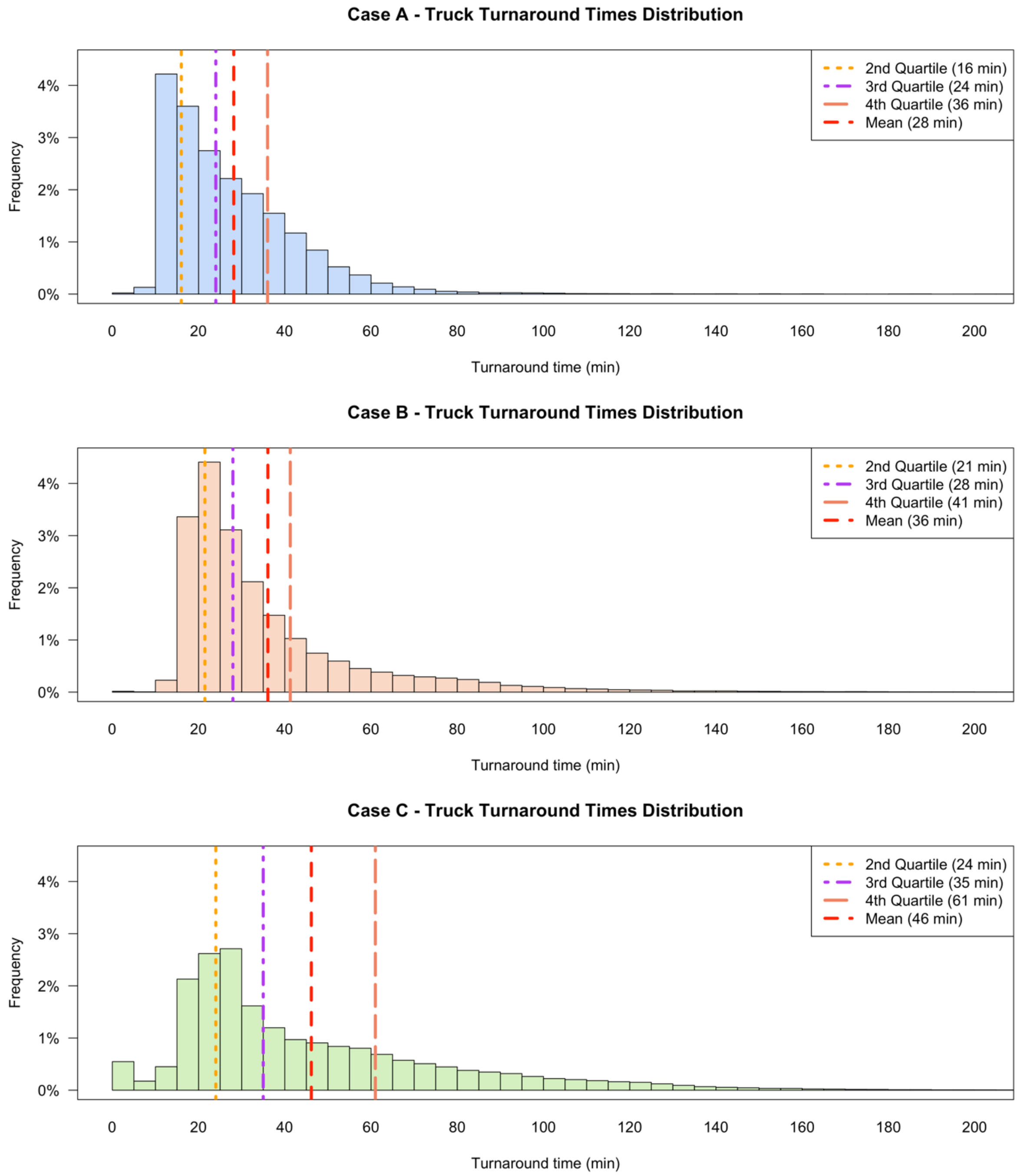


Figure 38 Truck Turnaround Times Distributions

The inspection of truck turnaround times data revealed marked differences between the turnaround times average values as well as the distribution shapes. The truck turnaround time distributions for all cases were visualised in Figure 38. In Case A, approximately 65% of the observations lie between the 10- and 30-minute boundary whereas the majority of the rest are higher. The average turnaround time across the data is 27.96 minutes. In Case B, approximately a quarter of the truck turnaround times are under 21-minutes, the majority of these between 15- and 21 minutes. Half of the truck turnaround times are between 21- and 41-minutes whereas the rest are higher. The average turnaround time across the data is 36 minutes. Finally, in Case C, approximately a quarter of the truck turnaround times are under 24-minutes, the majority of these between 15- and 24 minutes. Half of the truck turnaround times are between 24- and 61-minutes whereas the rest are higher. The average turnaround time across the data is 46 minutes.

The average truck turnaround time may misrepresent congestion. A large proportion of the truck turnaround times in all cases were in fact smaller than the average which was referred to in interviews (see Section 5.2.1.1.7). However, the variability of truck turnaround times was generally large, and usually biased towards high values. It was therefore suspected that the variability of truck turnaround times was in fact partially responsible for some of the reported congestion impacts in terms of uncertainty (see Section 5.2.1.2.3).

The truck arrival frequency at the terminals in each case study were investigated next.

5.3.1.3 Truck Arrival Frequency

The truck arrival frequency distributions in all cases were right skewed with a large proportion of arrivals in less than 5 minutes from one another. Given that unloading durations at all three terminals were anecdotally situated between 10 and 15 minutes per truck, it was highly likely that the frequent arrival of trucks was a contributor to congestion. High arrival frequency of trucks can also be used as an indicator for the level of coordination both within and organisation and between organisations.

The truck arrival frequency distributions in all cases were right skewed with a large proportion of arrivals in less than 5 minutes from one another. In Case A, the average truck arrival frequency at the terminal was 8.7 minutes, however, more than 62% of the trucks arrived at intervals smaller than the average. 41% of all arrivals were under 5 minutes of one another and 27% of all arrivals were under 3 minutes of one another. In Case B, the average truck arrival frequency at the terminal was 9 minutes, however, more than 65% of the trucks arrived at intervals smaller than the average. Half of all arrivals were under 5 minutes of one another and 25% of all arrivals were under 3 minutes of one another. Trucks arriving in such a close sequence from one another would likely have to wait for terminal infrastructure to become available. In Case C, the average truck arrival frequency at the terminal was 9 minutes, however, more than 65% of the trucks arrived at intervals smaller than the average. Half of all arrivals were under 5 minutes of one another and 25% of all arrivals were under 2 minutes of one another. Trucks arriving in such a close sequence from one another would likely have to wait for terminal infrastructure to become available.

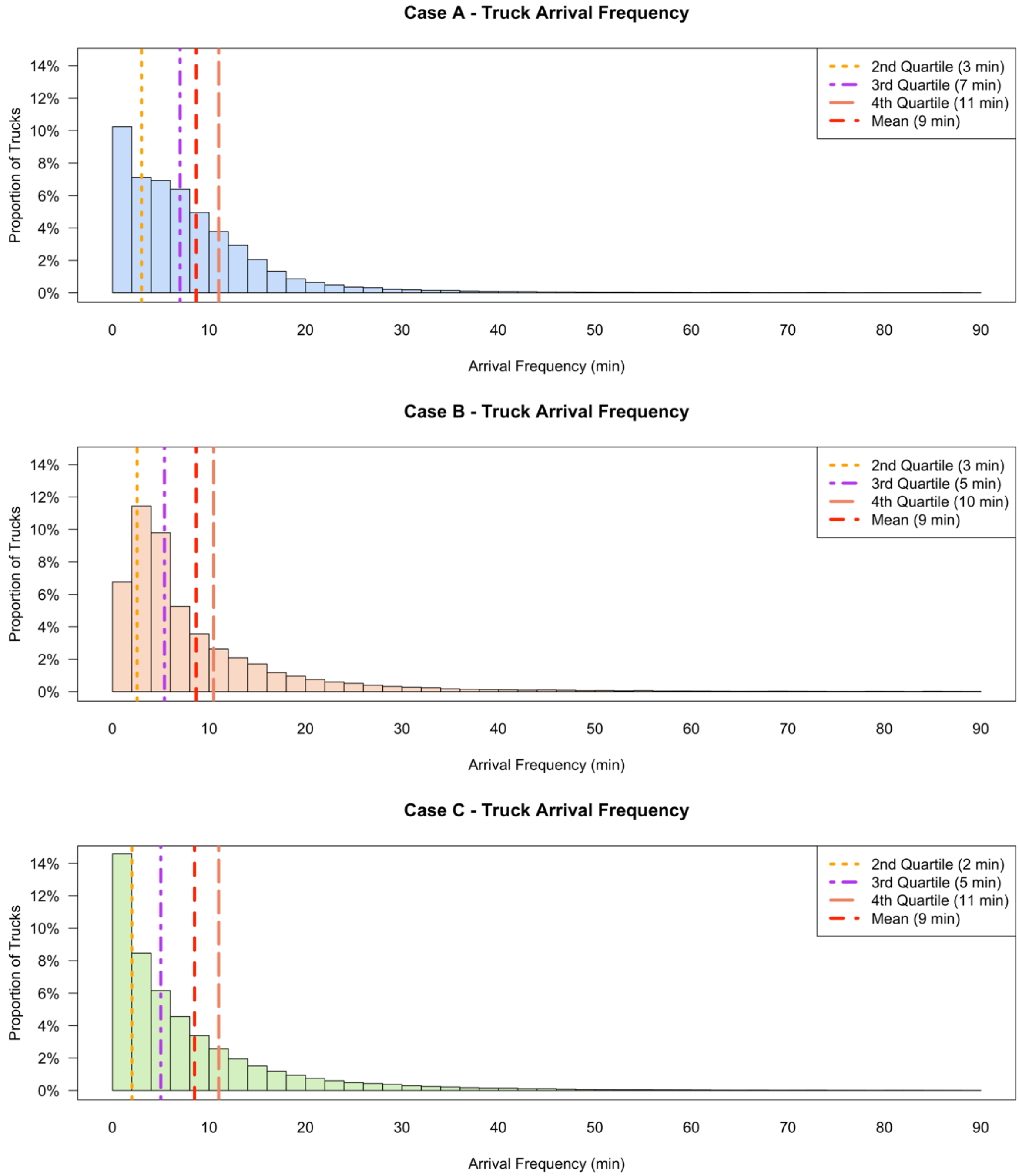
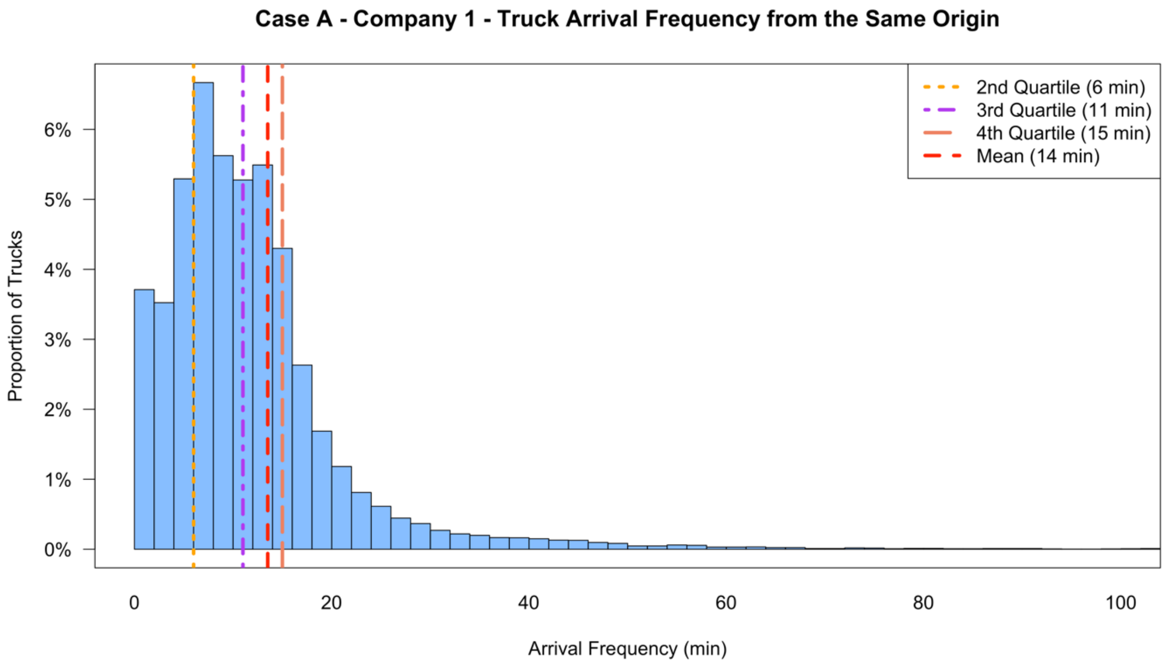


Figure 39 Truck Arrival Frequency Distributions

Trucks originating from the same source, often delivering products for the same customers, would arrive in close sequence to one another. There was evidence for coordination challenges within organisations which were in accordance with insights revealed during Stage 1: Exploration (Section 5.2.1.1.4). Figure 40 illustrates the arrival frequency of trucks arriving from the same origin in Case A. This appeared to be the case more so for Company 2 than Company 1 which maintained a more consistent arrival frequency.



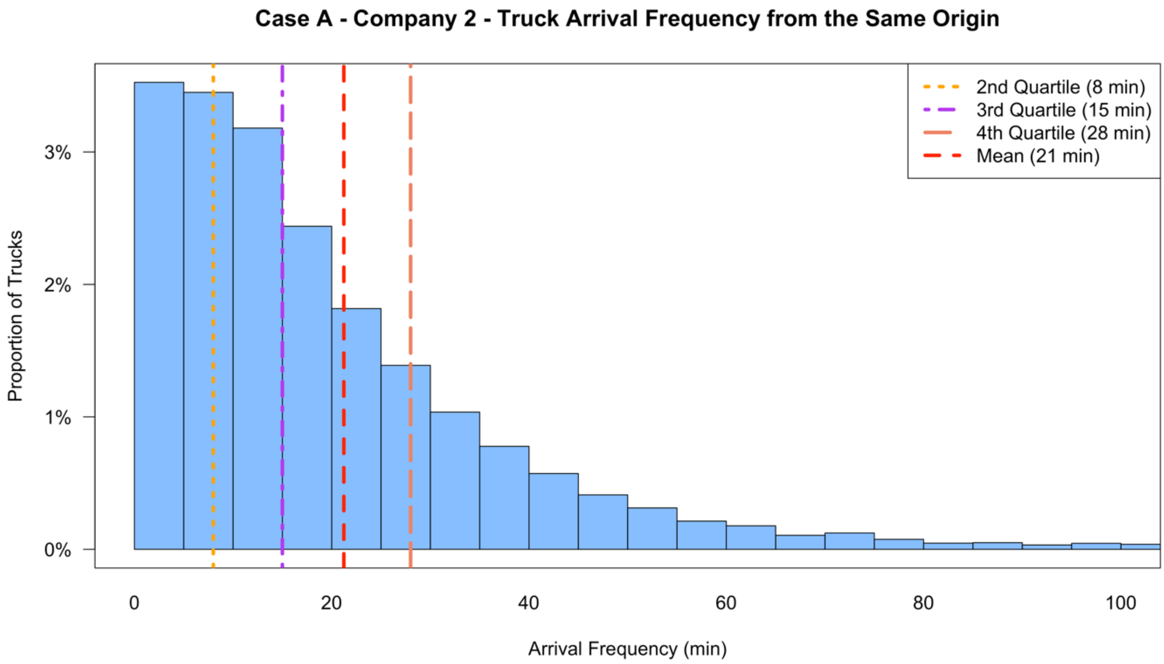


Figure 40 Case A - Truck Inter-Arrival Times from the Same Origin

Figure 41 illustrates the arrival frequency of trucks arriving from the same origin in Case B. The origins in this case are forest coupes from which log-trucks deliver to the inland terminal. Generally, a forest coupe is served by a haulage contractor. The coupes are clustered on distance based on the number of deliveries a truck is expected to do from a distance range. For examples, truck operators are expected to do at most 2 daily deliveries from coupes located more than 161 kilometres from the inland terminal.

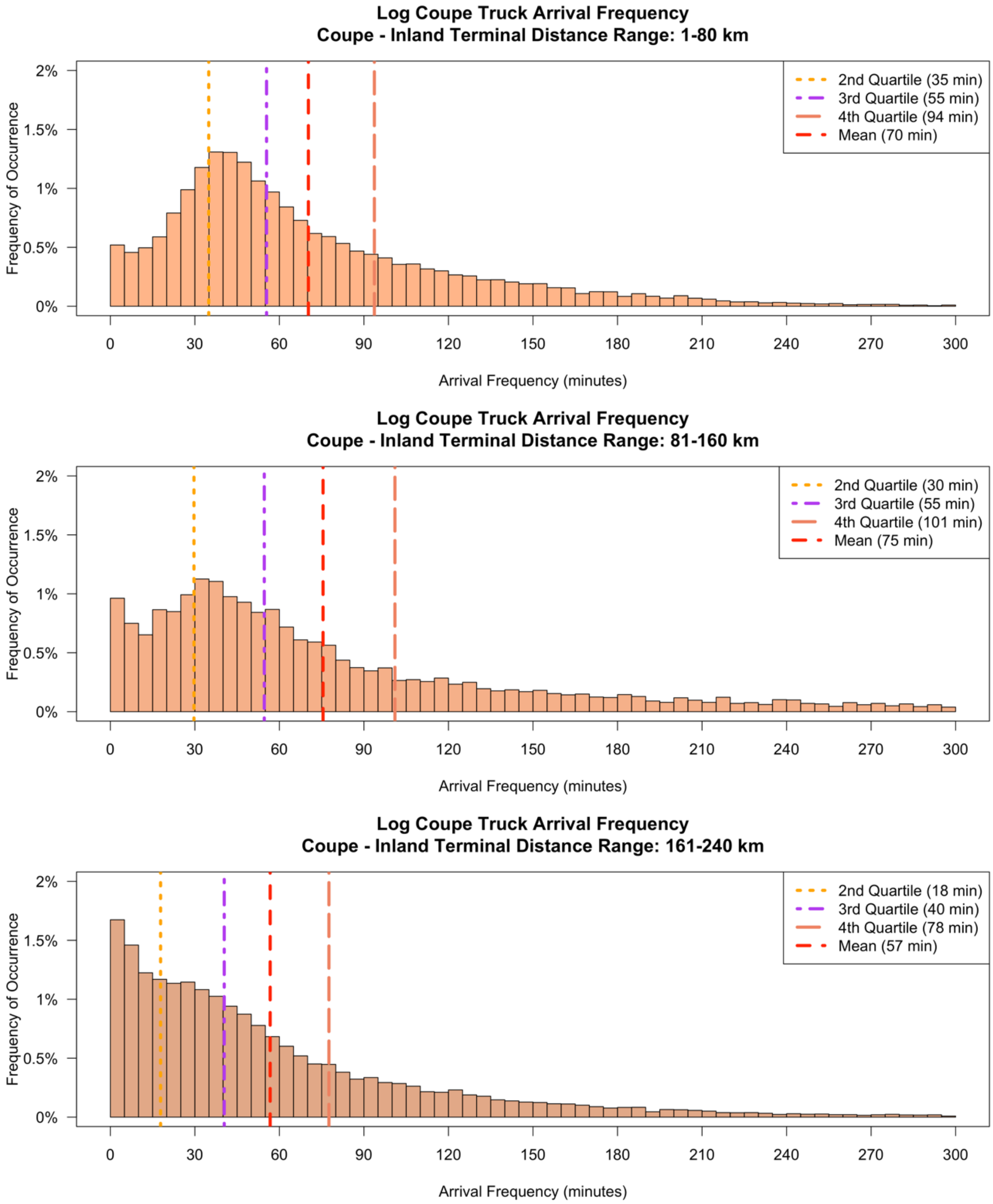


Figure 41 Case B - Truck Arrival Frequency from the Same Origin

A high proportion of trucks arriving from long distances were more frequently arriving in closer proximity to one another than in the other cases**.** The truck arrival frequency distribution shape is different in the 161-240km range, when compared to the other distance ranges. This result supported insights regarding coordination within organisations from Stage 1: Exploration (see Section 5.2.1.1.4). However, this result cast doubt regarding the impact of supply chain flexibility (see Section 5.2.1.1.6), and particularly to the positive impact on congestion due to the variation of production sites distances.

The hourly truck arrivals at the terminals in each case study were investigated next.

5.3.1.4 Hourly Truck Arrival Frequency

The hourly truck arrival frequency at the terminals in each case study revealed differences between the operating times of each terminals and the times in which most trucks arrived. In Case B, truck arrivals increased starting from 3am, in spite of the fact that the terminal opened only at 6am. Similarly, truck arrivals plateaued in the late afternoon, however the terminal was open until 11pm. In Case C, a similar pattern is observed, in spite of the fact that the terminal was open 24-hours a day.

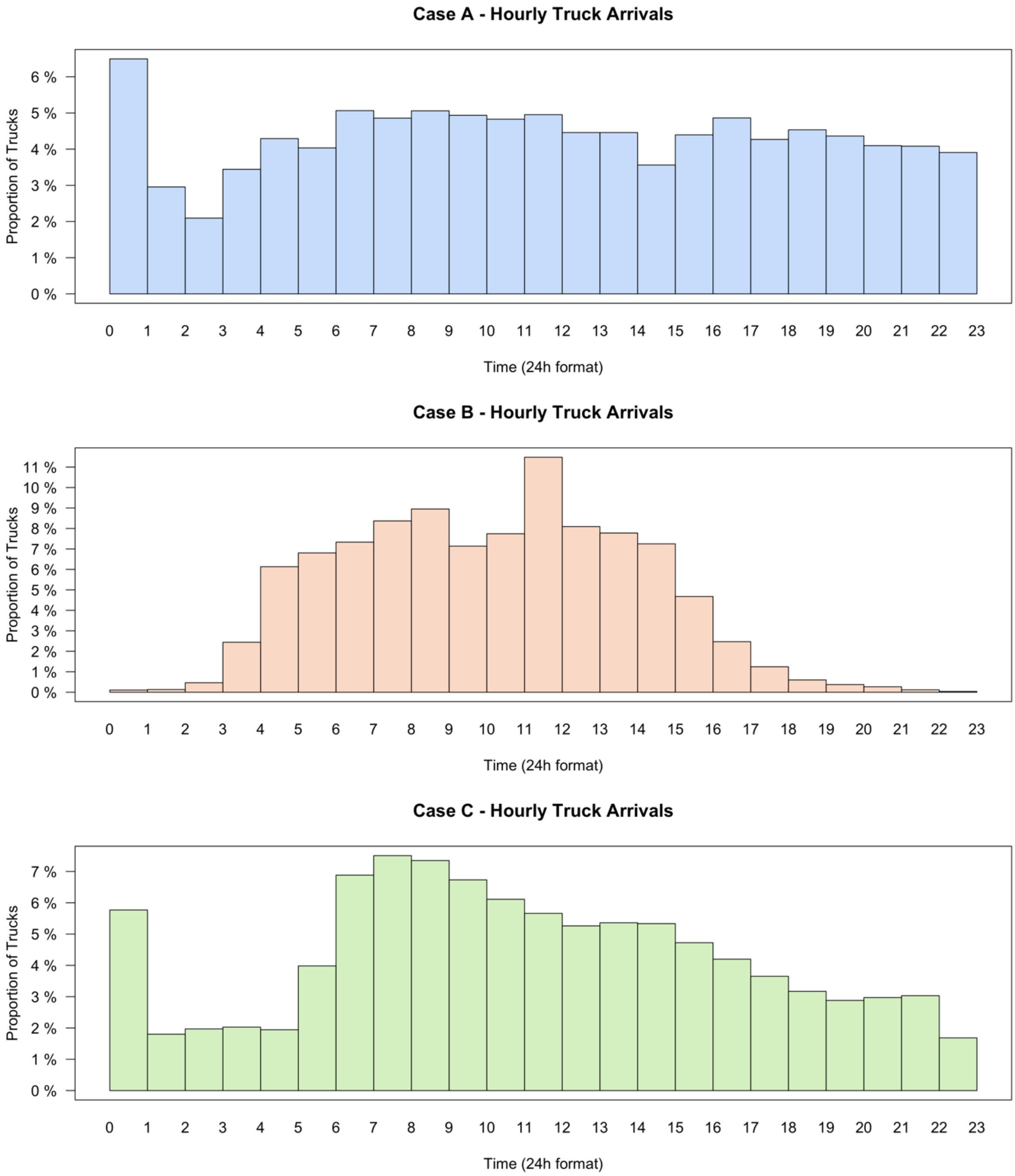


Figure 42 Hourly Truck Arrivals Distributions

The hourly truck arrival distributions off all case studies are illustrated in Figure 42. The truck arrival distribution in Case A appears relatively uniformly spread across the hours of the day. The terminal in Case A is open 24-hours a day. The large percentage of trucks recorded at 12pm is likely due to manual data inputs. The relatively uniform spread of truck arrivals during the day can be related to the operating hours of the mills supplying the terminal that are also open 24-hours per day. In Cases B and C, there are however significant differences in the hourly truck arrival patterns.

In Case B, truck arrivals appear to begin arriving from 3am even though the terminal is only open from 6am. Therefore, while the proportion of trucks arriving in each hour before 6am is not extremely large compared to other time intervals, the fact that these trucks are only serviced starting from 6am indicates a significant potential for congestion. Discussions with terminal staff revealed that some truck drivers would arrive before the terminal opening times to ensure that they unload as soon as possible and have the possibility to deliver at least another time during their 12-hour shift. After 4pm the number of trucks arriving at the terminal decreases significantly, even though the terminal is open for 6 additional hours. The largest proportion of trucks would be received in a 10-hour interval, between 6am and 4pm, whilst the remaining 6-hours, the terminal would experience very low levels of utilisation.

In Case C, the terminal operates and is open for customer deliveries 24-hours per day. The proportion of truck arrivals between 10pm and 5am remains relatively stable and low when compared to the other time intervals. In particular, the 6am-10am time intervals appear to be the busiest, with more than a third of trucks arriving during that time. Approximately 80% of trucks arrive at the terminal between 6am and 4pm. Therefore, the largest proportion of trucks would arrive in a 10-hour interval, between 6am and 4pm, whilst the remaining 14-hours, the terminal would experience moderate to low levels of utilisation.

In Cases A and C, the researcher observed a spike in truck arrivals at midnight. Informal discussions with terminal staff regarding the data revealed that many of the observations at 12pm were manual inputs necessary due to driver or system errors. Where possible, these observations were excluded from the analysis.

The results of the discrete event simulation model are discussed next.

5.3.2 Terminal Simulation Scenario Analysis[10]

The simulation was based on data collected from Case A. The simulation's inputs, specification, assumptions logical flow and validation procedures are described in Sections 4.6.2.1. The unavailability of suitable data prevented the researcher from replicating the model based on the terminals from Cases B and C. However, given that there are a series of similarities between the terminals in the three cases, it was considered likely that the results would be somewhat transferrable across cases.

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[10] This section draws from Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P. "Using Discrete-Event Simulation to Compare Congestion Management Approaches at a Port Terminal." Simulation Modelling Practice and Theory Journal, UNDER REVIEW

The discrete-event simulation model of the bulk cargo marine terminal truck unloading operations aimed to: (1) improve understanding with regards to the impact of stochastic components (mainly truck arrival, unloading and weighing times) on the overall unloading performance and (2) evaluate the sensitivity of the truck unloading operations at the terminal to changes in these stochastic components or terminal setup.

Six congestion mitigation scenarios were considered. Each of the six scenarios was considered under eight progressively increasing terminal throughput scenarios. The first throughput scenario resembled the situation observed at the terminal given the available data. The results of the scenarios analysis were primarily used to illustrate the potential impact of various approaches, each addressing a different aspect of terminal operations, and direct the stakeholders' attention to the approaches that appeared most effective to alleviate congestion. The landside congestion management measures included in the scenario analysis are:

- Scenario 1: The introduction of a **terminal appointment system (TAS)** was modelled by introducing arrival slots for each truck. The length of one slot was equal to the average IAT of trucks in that throughput scenario (e.g. a slot was 10-minute-long in the base scenario where the IAT average was 10 minutes). A stochastic arrival component was added through a normal distribution with $\mu=0$ and $\sigma=2.5$ to simulate potential small deviations from the slot start time. All trucks modelled in the scenario used the appointment system and no missed appointments or walk-ins (i.e. trucks arriving without appointments) were considered.
- Scenario 2: The introduction of an **integrated weigh-bridge database (IWB)** that would store the empty weights of trucks was modelled by removing the weighing out stage of trucks. Under this system, trucks would weigh upon arrival at the terminal and the net payload would be directly calculated using stored truck information. Once trucks are emptied, operators may drive directly to reload without the requirement to weigh again. This scenario is inspired from automation technology solutions observed in the container terminal literature.
- Scenario 3A: The **extension of the conveyor system (CON)** with another hydraulic ramp connected to the same conveyor was also considered. Another identical ramp with the 2 already present on site would allow concurrent unloading of 3 trucks, subject to the limitations of the conveyor belt system.
- Scenario 3B: A **ramp expansion (RAM)** is modelled by introducing a separate unloading system comprising of a hydraulic ramp and conveyor belt that can operate independently of the existing system was also modelled. Each unloading system would be dedicated to one customer, therefore separating truck flows between the two companies. Both unloading system scenarios are terminal capacity improvements.
- Scenario 4: The use of **higher capacity trucks (HCT)** with a 45-ton payload for all transportation tasks and the replacement of lower capacity, 32-ton trucks is also modelled.
- The base scenario with which all comparisons are made is where **no congestion management intervention (NOINT)** is undertaken.

The scenarios are not mutually exclusive and could be applied in combination. However, the purpose of this simulation was to understand the sensitivity of terminal operations to the individual approaches. Consequently, each congestion mitigation scenario only considered one approach at a time. Furthermore, considering one landside congestion management approach at a time in each scenario is also a way of acknowledging the economic and time constraints faced by the case study participants. The existing terminal layout and the modelled scenarios are visualised in Figure 43.

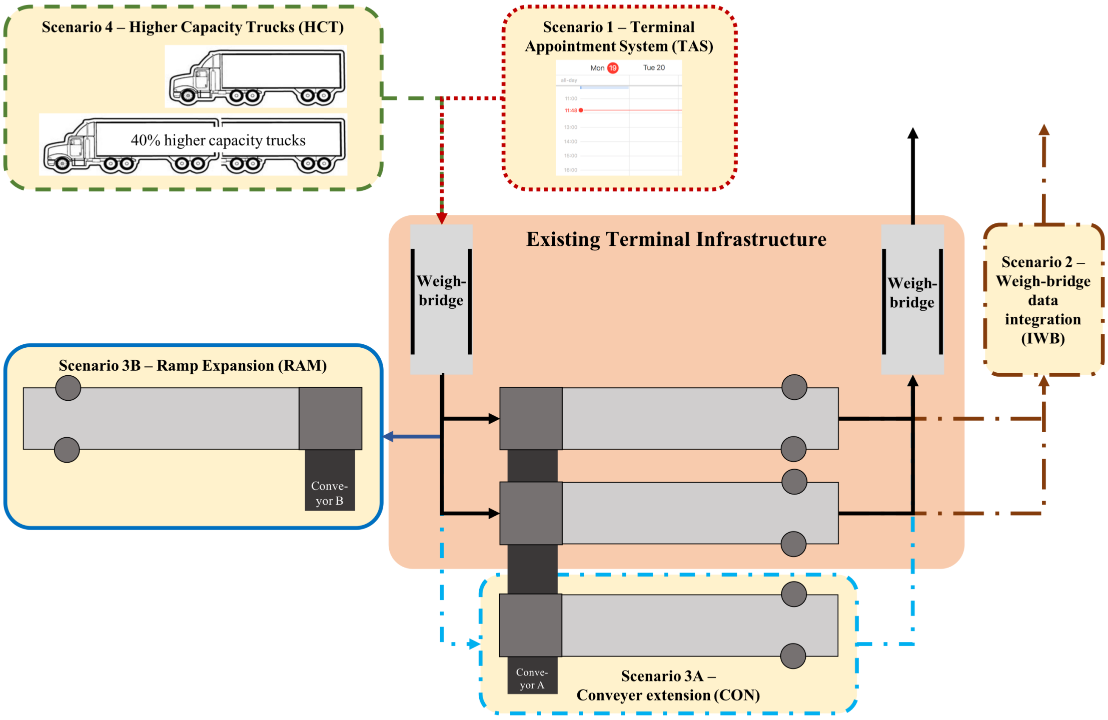


Figure 43 Case A - Landside Congestion Management Scenarios

The sensitivity of the landside congestion management approaches to increasing throughput was by applying a scaling coefficient on the base IAT distribution (gamma distribution k=1.49, θ=6.97, μ=10) of 0.9, 0.85, 0.8,0.775,0.75, 0.725 and 0.7. The scaling coefficient progressively reduced the average IAT from 10 minutes in the base case to 7 minutes while maintaining the same distribution shape. The throughput scenarios are identified based on the mean IAT. In total 48 combinations were considered in the simulation scenario analysis. For each combination, the simulation was run for 50 iterations with each iteration representing one year of terminal operations. The performance of landside congestion management approaches was measured against four key performance indicators:

(1) Average truck turnaround times across the year.
(2) Average truck waiting times across the year.
(3) Truck turnaround time reliability which measures the percentage of trucks unloaded by the terminal in less than 25 minutes respectively. The 25-minute mark was chosen considering the round-trip driving time between the production facilities and the terminal and the drivers’ 12-hour working window, an increase in terminal turnaround time over 25 minutes impacts the number of daily deliveries that can be achieved.

Specifically, trucks running on a 40-minute round-trip loop may only be able to achieve 10 instead of 11 daily deliveries, while trucks running on a 90-minute round-trip loop may only achieve 5 instead of 6 daily deliveries.

(4) Carbon dioxide (CO_2) emissions of idling truck engines during waiting.

The statistical significance of the differences between scenarios under each truck arrival frequency indicator was compared with ANOVA and pair-wise differences were subsequently tested with the Tukey test using a significance threshold of 0.05 (see details in Appendix E).

5.3.2.1 Simulation Results

The simulation model results revealed that congestion levels and truck turnaround times are highly sensitive to the terminal's throughput increase. The maximum capacity of the terminal was simulated by increasing the arrival frequency of trucks to the point where trucks would not be processed (simulated at approximately 2.4 million tons per year). As the terminal throughput increases from 1.6 towards 2 million tons, truck turnaround times increase by 43% (to 33 minutes) as the throughput increases by 25% (to 2 million tons/year). However, each subsequent throughput increase has a progressively larger impact on turnaround times. A small throughput change of 60,000 tons (IAT 8 to IAT 7.75) generates an increase in turnaround times by more than 15%. Similarly, while the difference in throughout between the IAT 7 and IAT 7.25 is only 75,000 tons, the difference in turnaround times between the two scenarios is 30 minutes, a 57% increase. The model results are summarised in Table 12.

The comparison between the IAT 10 and IAT 7 scenarios for an increase in throughput of 40% the increase in turnaround times is close to 280%, with the greatest proportion of the turnaround time increase attributed to the last 150,000 tons of throughput. Truck-related CO_2 emissions also increased 16-fold between the IAT 10 and IAT 7. Therefore, when terminal capacity is available to absorb operational variability in a dynamic system, congestion has a limited impact on turnaround times. However, then the system approaches capacity, the consequences of congestion are more severe as it can disrupt operational flows and, in extreme cases, bring operations to a halt. The turnaround time sensitivity to increasing throughput is depicted in Figure 44.

Table 12 Simulation Scenario and Sensitivity Analysis Results

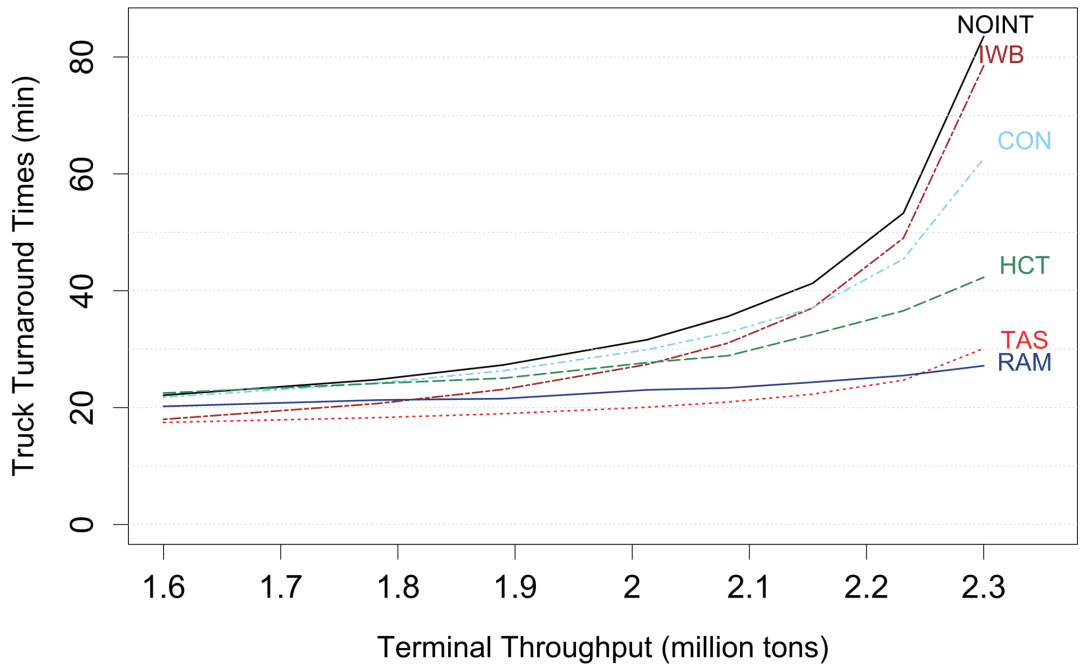
IAT[A]	Scenario	Trucks	Throughput ('000 tons)	TTT (min)[B]	TTT SD[C]	Wait (min)[D]	Rel. 25[E]	CO_2 (t/yr) [G]
10	**NOINT**	52,384	1,598	23	10	6	75%	23
	IWB	52,454	1,601	20	9	6	83%	22
	TAS	52,559	1,604	19	5	1	93%	5
	HCT	42,719	1,620	24	9	5	75%	15
	CON	52,389	1,599	23	9	6	76%	22
	RAM	52,385	1,599	21	7	4	84%	15
9	**NOINT**	58,417	1,783	26	12	9	66%	37
	IWB	58,395	1,782	23	12	8	74%	36
	TAS	58,398	1,782	19	6	2	91%	9
	HCT	47,642	1,807	25	11	7	68%	24
	CON	58,450	1,784	25	11	8	68%	34
	RAM	58,443	1,784	22	8	5	80%	21
8	**NOINT**	65,964	2,013	33	19	15	49%	76
	IWB	65,957	2,013	30	19	15	58%	74
	TAS	65,698	2,006	21	7	4	84%	19
	HCT	53,736	2,038	30	15	11	56%	43
	CON	65,972	2,013	31	17	14	53%	67
	RAM	66,069	2,016	24	10	6	74%	31
7.5	**NOINT**	70,479	2,151	36	28	25	36%	130
	IWB	70,605	2,155	33	29	26	43%	134
	TAS	70,077	2,140	22	9	6	74%	32
	HCT	57,466	2,180	31	19	15	47%	65
	CON	70,491	2,151	34	24	21	41%	109
	RAM	70,477	2,151	24	11	8	69%	40
7.25	**NOINT**	73,046	2,229	55	41	37	27%	202
	IWB	73,044	2,229	51	40	36	33%	198
	TAS	72,492	2,213	26	11	8	66%	45
	HCT	59,511	2,257	38	23	19	40%	84
	CON	73,056	2,230	47	32	29	32%	158
	RAM	73,078	2,231	26	12	8	66%	46
7	**NOINT**	75,782	2,313	83	67	66	17%	369
	IWB	75,732	2,311	82	76	68	21%	381
	TAS	75,082	2,291	31	16	14	51%	77
	HCT	61,662	2,339	44	28	25	34%	115
	CON	75,693	2,309	63	49	46	23%	258
	RAM	75,765	2,312	27	12	9	64%	52

[A] Inter-Arrival Time; not all IAT scenarios presented to conserve space; [B] Average Truck Turnaround Times; [C] Standard deviation of Truck Turnaround Times; [D] Average Waiting Times; [E] Truck Turnaround Time Reliability - % of trucks unloaded in 25 minutes or less; [G] Truck Engine Idling CO2 Emissions per Year (tons) – truck emission factors obtained from the Port of Los Angeles (Starcrest Consulting Group, 2018);

NOINT = no intervention; IWB = data integration; CON = conveyor extension;
TAS = appointment system; RAM = ramp expansion; HCT = high capacity trucks;

It is important to recognise that given the nature of the landside congestion management approaches modelled, the terminal capacity utilisation was not an adequate performance metric. The terminal's capacity is affected by the capacity of physical infrastructure and the trucks' payload capacity. A conveyor extension (COM) or ramp expansion (RAM) of the terminal's infrastructure is expected to influence the capacity of the terminal. Similarly, higher capacity trucks (HCT) reduce the number of truck arrivals while delivering similar volumes at the terminal and are expected to lower the terminal capacity utilisation.

The two technology options, namely weigh-bridge data integration (IWB) and the terminal appointment system (TAS) achieved the highest reduction in turnaround times in the baseline throughput scenario (IAT 10). Both approaches generate a reduction of average turnaround times by approximately 20% compared to the existing situation (NOINT). Both approaches were also successful in increasing the unloading reliability (Rel.25) by 8 and respectively 18 percentage points. Interestingly however, although the turnaround time reduction is similar, the reduction in CO_2 emissions of the TAS is significantly larger than the IWB. The IWB led to a less than 5% reduction in emission while the TAS led to more than 80% reduction in emissions. A closer look at the data revealed that while the IWB reduced processing times, the approach did not affect the structure of the truck turnaround and waiting times. The evolution of the terminal's throughput and turnaround times are shown in Figure 44.



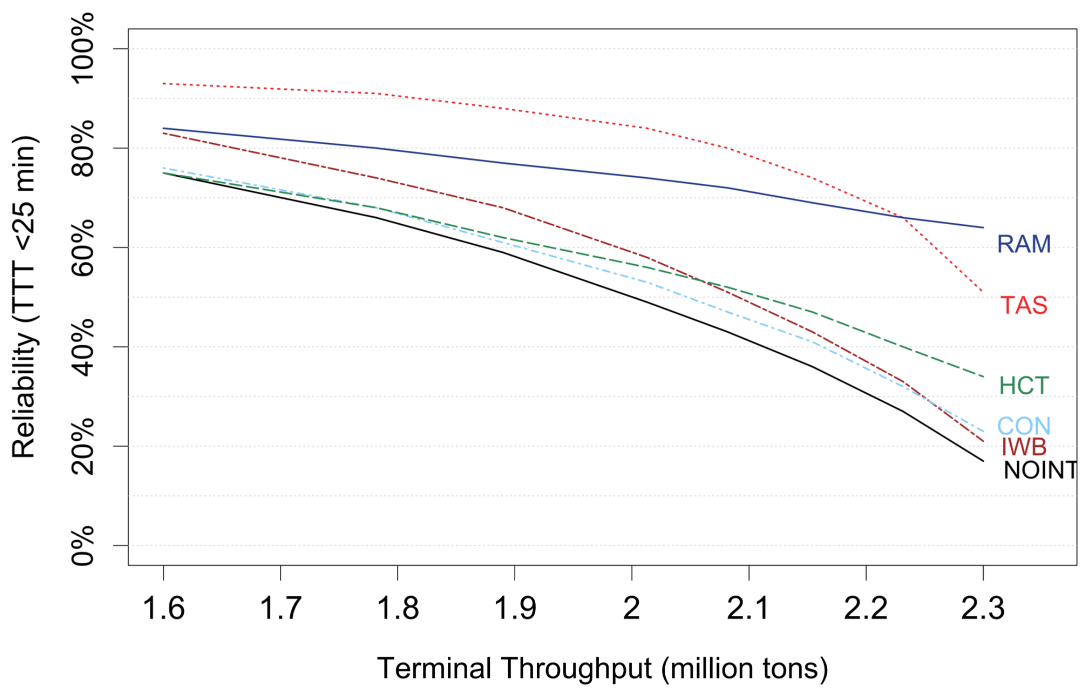
NOINT = no intervention; IWB = data integration; CON = conveyor extension;
TAS = appointment system; RAM = ramp expansion; HCT = high capacity trucks;

Figure 44 Scenario Analysis Turnaround Time Comparison

Across most subsequent throughput growth scenarios, the TAS remained the technology approach that had most impact on turnaround, waiting times as well as emissions. In IAT 7.25 scenario, the appointment system (TAS) yielded a comparable performance with the ramp expansion (RAM) in terms of turnaround times and emissions.

Both the conveyor extension (CON) and ramp expansion (RAM) initially had a lower than expected impact on turnaround times. This was an unexpected outcome, particularly in the case of the terminal expansion which essentially separates the two companies' flows and introduces substantial additional capacity at the terminal. The average turnaround time and reliability (Rel.25) of CON in the IAT 10 scenario are approximately 10% less than RAM. The truck CO2 emissions are however close to 25% less in CON than RAM.

As the terminal throughput increases however, the performance of the CON is significantly better than the RAM. CON are consistently the second-best alternative from the five tested in the IAT 9 to 7.25 scenarios in terms of turnaround time, reliability and emissions. As the terminal throughput increases to 2.3 million tons (IAT 7), CON yielded the lowest turnaround and waiting times, emissions and the highest turnaround time reliability. The sensitivity of the reliability indicator to increasing throughput is visualised in Figure 45.

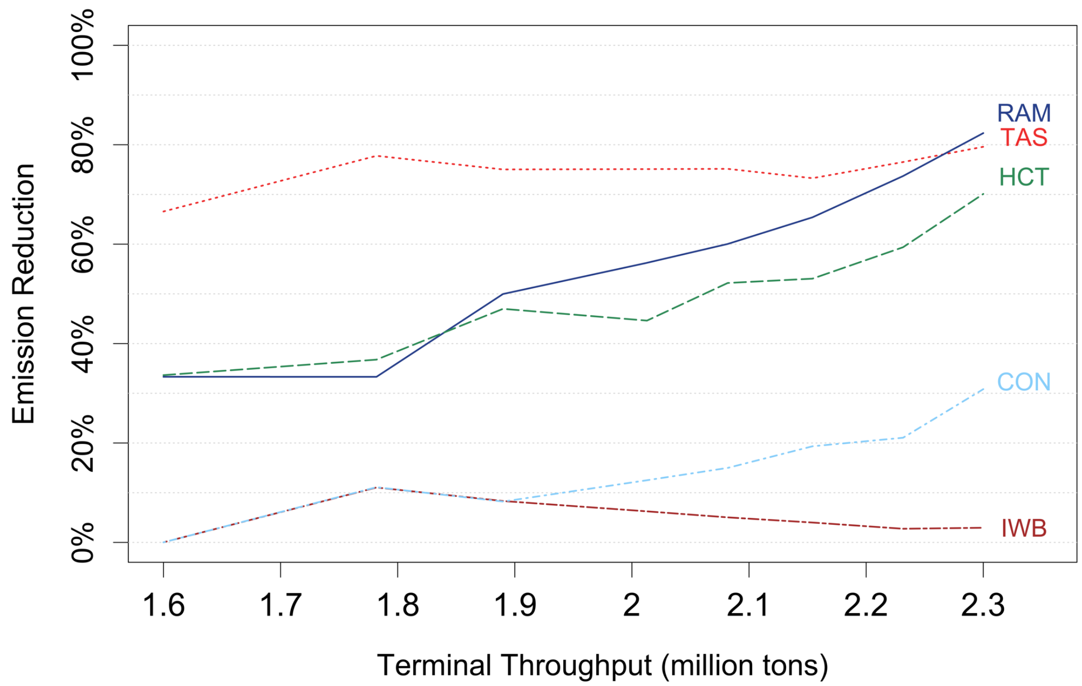


NOINT = no intervention; IWB = data integration; CON = conveyor extension;
TAS = appointment system; RAM = ramp expansion; HCT = high capacity trucks.

Figure 45 Scenario Analysis Comparison of Turnaround Time Reliability

Although not traditionally considered a congestion mitigation approach, higher capacity trucks (HCT) have yielded improvements in turnaround time and emissions. The majority benefits appear to stem from the reduction of the number of truck arrivals which entail fewer opportunities for truck arrivals to overlap and also fewer operating trucks generating emissions.

The impact on truck emissions of the modelled landside congestion management approaches varies in relation to the terminal throughput and truck arrival frequency. The TAS can consistently yield emission improvements by 70-80% compared to NOINT, while the IWB generally provides a significantly smaller improvement between 5-15%. Interestingly however, the emission impact of RAM and HCT in comparison to NOINT significantly increases as the terminal throughput grows. The impact on truck emissions of the landside congestion management approaches modelled in this research is visualised in Figure 46.



NOINT = no intervention; IWB = data integration; CON = conveyor extension;
TAS = appointment system; RAM = ramp expansion; HCT = high capacity trucks.

Figure 46 Scenario Analysis Emission Reduction Compared to No Intervention

The next subsection explores the appointment system parameters and user behaviours with respect to the use of a TAS.

5.3.2.2 The Impact of Appointment System Parameters and User Behaviours[11]

During the first workshop in Case A, some participants remarked that an important assumption of the modelling was that, in order for the appointment system to be effective, the uptake of the appointment system should be 100% otherwise it would fail, as illustrated by the exchange between participates below:

1. [11] This section draws from Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P (2019) Using Discrete-Event Simulation to Explore the Impact of User Behaviours on the Effectiveness of a Terminal Appointment System. In 33rd European Simulation and Modelling Conference, ESM 2019. EUROSIS-ETI

> **Elliott (Forestry Company/Case A):** "*You* [referring to the researcher] *did model that given that there's only 2 companies that currently deliver wood-chips, you modelled that 100% of those 2 companies will take up this appointment system."*
> **Frank (Terminal Operator/Case A):** "*It can't be one.* "
> **Elliott:** "*It can't be one exactly.*"
> **Frank:** "*It's either all or we might just as well continuing what we're doing.*"

The belief that a TAS would be ineffective if some organisations do not abide by its rules appeared to be shared across participants. Therefore, it was important to understand whether this belief was founded in evidence. Consequently, two important assumptions of the TAS approach were progressively relaxed.

1. that all truck arrivals would be appointed and
2. all arrivals would be within a punctuality threshold.

The simulation model was modified (see Section 4.6.2.1) to allow for the impact of three factors to be included in the scenario analysis: and system parameters (appointments per time window) and driver behaviours (unplanned appointments and punctuality). These factors were also considered in the landside congestion management literature for containers (see Section 3.3.3):

- **Number of appointments per time window.** Three values were included for each one-hour time window,
  (a) 6 appointments/hour (low frequency) – equivalent to the IAT 10 scenario (see Section 5.3.2.1),
  (b) 7 appointments/hour (medium frequency) - equivalent to the IAT 8.5 scenario,
  (c) 8 appointments/hour (high frequency) - equivalent to the IAT 7.5 scenario.
  In the cases where all appointments were unplanned, an inter-arrival time distribution that would provide similar arrival frequency was used.
- **Planned/Unplanned arrivals.** The proportion of planned and unplanned arrivals was varied in 20% increments between 0% (all un-appointed arrivals) and 100% (all appointed arrivals).
- **Arrival punctuality.** Punctuality was modelled by adding a stochastic component to each appointed arrival time. Three normal distributions were used to simulate truck arrival punctuality, similar to the approach presented in (Ramírez-Nafarrate *et al.*, 2017):
  (a) High punctuality: 95% of arrivals are within 5 minutes of the appointment time
  (b) Medium punctuality: 2/3 of arrivals are within 5 minutes of the appointment time
  (c) Low punctuality: 1/3 of arrivals are within 5 minutes of the appointment time.

The scenario analysis included combinations of the 3 factors and resulted in 47 scenarios. Each scenario was run 50 times and each iteration simulated a year of operations.

The results of the simulation model in terms of average truck turnaround time for the scenarios tested are presented in Figure 47. The scenario where an average of 6 trucks per hour arrive uncoordinated resembles the NOINT IAT 10 scenario in Section 5.3.2.1 and the situation empirically observed at the terminal.

The user behaviours and appointment proportions scenarios highlighted that it is sufficient for a relatively low proportion of operators to coordinate using the system in order to have a positive impact on the truck turnaround times. The positive impact is increased as the proportion of operators that use the appointment system increases and also increases with punctuality. Improved punctuality (from low to high) virtually doubles the expected percentual improvements of truck turnaround times in virtually all low arrival frequency scenarios.

Interestingly, the largest improvement in truck turnaround times was in the high arrival frequency scenario where a small proportion of operators started coordinating their arrivals using the TAS. The variability of turnaround times also decreases as the proportion of appointed arrivals increases. The variability of turnaround times, measured by the standard deviation, decreases in all three arrival frequency scenarios: For 6 trucks/hour, the decrease is approximately 40% between all unappointed and all appointed arrivals, close to 55% for 7 trucks/hour and approximately 66% for 8 trucks per hour. This discussion of truck turnaround times is largely based on the average. However, a larger set of descriptors have been used to explore the differences (see Appendix F).

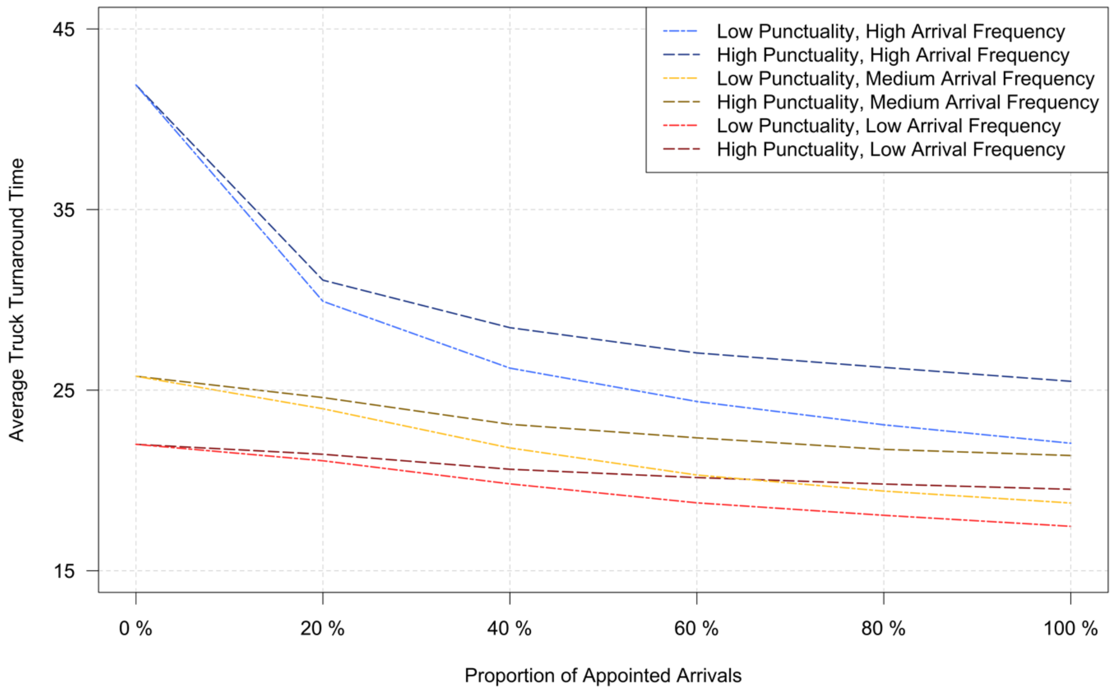


Figure 47 User Behaviours and Utilization Scenario Analysis

The next section discusses the core categories emerging during the coding process drawing on the principles of grounded theory of the workshops data.

5.3.3 Analysis and Preliminary Core Categories

This section presents the analysis and the preliminary core categories emerging from the coding process drawing on the principles of grounded theory. This analysis step consisted of open axial and selective coding of the data emerging from semi-structured interviews and produced a series of preliminary axial and core categories which are discussed below. The preliminary core categories are: congestion factors, congestion impacts and consequences and the role of information systems.

5.3.3.1 Congestion Factors

The CONGESTION FACTORS core category refers to aspects of terminal and supply chain operations that are conducive to the appearance of congestion. Figure 48 illustrates the axial codes and their relationships emerging during Stage 2: Design Workshops within the CONGESTION FACTORS core category.

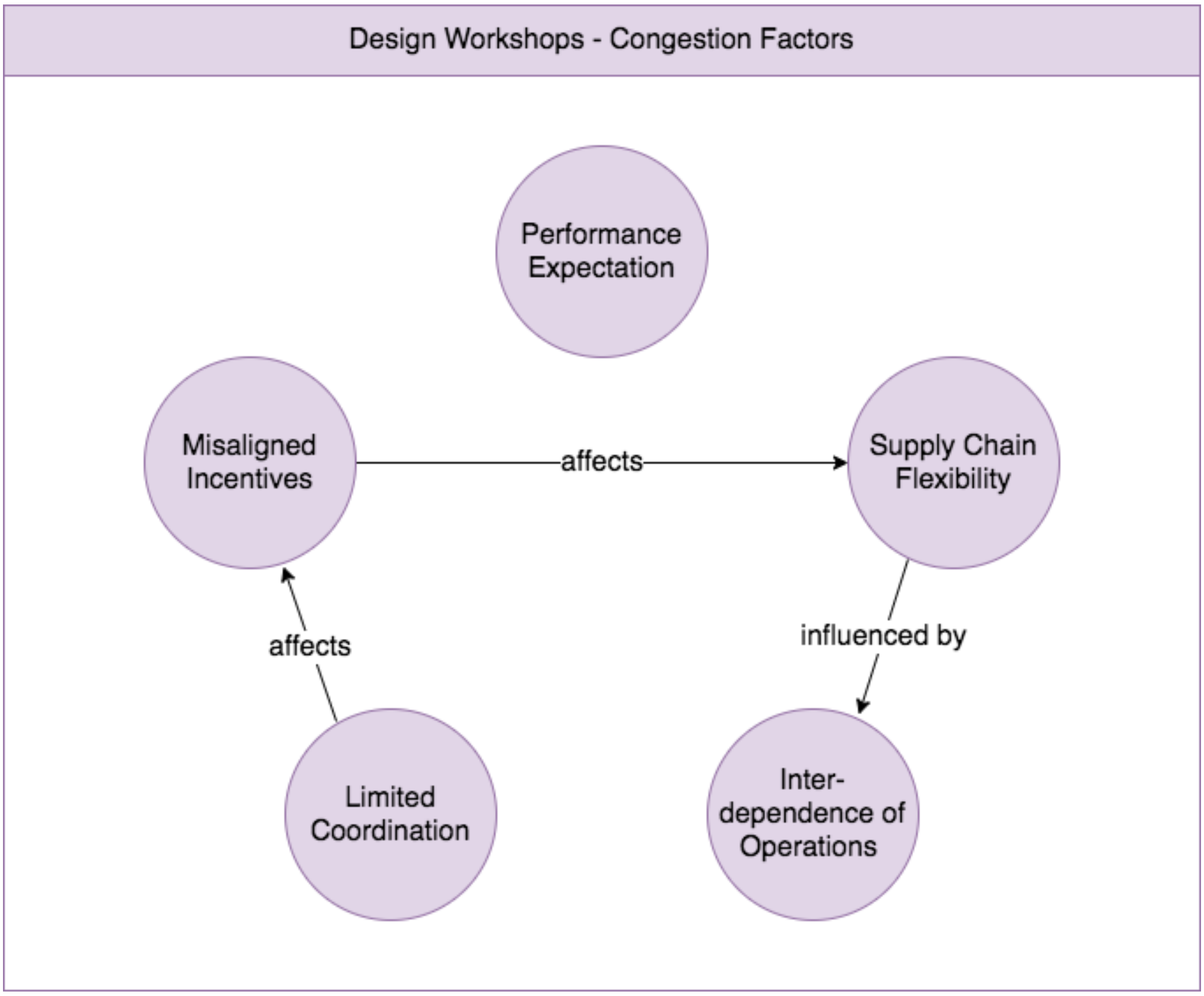


Figure 48 Stage 2: Design Workshops - Congestion Factors Axial Codes

There were five axial codes associated with this core category: *INTERDEPENDENCE OF OPERATIONS*, *LIMITED COORDINATION*, MISALIGNED INCENTIVES, *SUPPLY CHAIN FLEXIBILITY* and *PERFORMANCE EXPECTATIONS.*

5.3.3.1.1 Interdependence of Operations

The interdependence of supply chains emerged as a principal congestion factor in the workshops. The influence of interdependence was particularly recognised in Cases B and C. James account summarises how congestion is affected by interdependence:

> **James (Chipping & Haulage Contractor/Case C):** "*Port congestion isn't the issue, it's the by-product* […] *This is not a port congestion issue; this is a harvesting issue that's manifesting in haulage.'*"

Changes in the in-field chipping operations and their requirements were considered as the main factors that led to the appearance of congestion. During the workshop, James provided several examples of the mechanisms through which in-field chipping affected transportation and congestion: the production tolerances had been decreased to the extent to which small production quality variations would cause a slow-down in deliveries at the terminal and the harvesting and consequently transportation times were restricted by wildlife protection and community regulations.

In Case B, David's account is illustrative of how the introduction of interdependence between in-field chipping and transportation generated several issues and facilitated the appearance of congestion. Both Cases B and C shared operational similarities with respect to in-field chipping and transportation.

> **David (Chipping & Haulage Contractor/Case B):** "*Many years ago, a certain director of this company made a statement 'we will build the roads, and you will be able to, the connectivity got put in place'* […] *All of a sudden, the B-doubles were getting live loaded. There was no separation. There were some efficiencies brought over, the transport was carting more, but it brought about inefficiencies for the chipping side. All of a sudden it was all linked, there wasn't round the clock haulage.*"

INTERDEPENDENCE OF OPERATIONS was influenced by SUPPLY CHAIN FLEXIBILITY. David's story also highlights how the reduction of supply chain flexibility in terms of the available transportation hours and the fact that wood chip production and truck loading would take place simultaneously facilitated the emergence of "*inefficiencies*" in the transportation process.

5.3.3.1.2 Limited Coordination

The limited coordination also emerged during the workshops. The limited coordination was primarily between the organisations. Interestingly, Charles' story illustrates how changes in the supply chain in terms of number of organisations created the need for coordination at an organisational level:

> **Charles (Forestry Company/Case A): "***Previously being a single-user port, the cartage contractor could manage it, he had his own appointment system. But, as soon as we put in multiple streams, each having their own appointment system, they aren't overlapping, they aren't communicating.*"

One major challenge with regards to coordination that was apparent in all three cases was regarding the responsibility of coordination, particularly across competing organisations performing similar tasks.

5.3.3.1.3 Incentive Misalignment

Misaligned incentives also contributed to the appearance of congestion. Arthur's story of tactical delivery plans is illustrative of misaligned incentives:

> **Arthur (Terminal Operator/Case B):** "*When we start in January, we've got this plan, we have to do 25,000 tons a week, every week. But then we get to February and realise we haven't done our 25,000 because we haven't had enough wood delivered. Then February, we amp it up. All our contracts go from January to December, so as we're going along in that year, we're amping it up. So, we're saying to our contracting parties, you gotta throw more wood* [...] *by December all hell breaks loose.*"

Because delivery expectations were not met that towards the end of the contractual period, the contractors were incentivised to deliver in order to fulfil their contractual agreements. The overlap of the end date of contractual agreements means that the increase in deliveries coincides for all contractors, therefore leading to congestion.

MISSALIGNED INCENTIVES were affected by the LIMITED COORDINATION. The increased delivery pattern towards the end of contractual period appeared to be of no surprise to the majority of the participants. However, few measures had been taken by the terminal operator or the contractors to mitigate the effect misaligned incentives.

5.3.3.1.4 Supply Chain Flexibility

The level of supply chain flexibility was considered a factor for congestion by many participants, primarily in Cases B and C where production and deliveries were not restricted to a limited number of sites. Flexibility could help relieve congestion whilst inflexibility could exacerbate its appearance, as highlighted in David's account:

> **David (Chipping & Haulage Contractor/Case B):** "*With logs you have lots of options. With chips there are a couple of variables: it depends where they are, in the shift as well. Where we can we'll either divert trucks to either our* X *yard or* Y *yard and we utilise the time. We might drop a shift off short, maintenance, washing, that type of things* [...] *but if they're en-route to the port 9 times out of 10 it will be just you go and wait. We might utilise the Portland yard to park up, ferry the drivers, and bring the afternoon shift early.*"

Particularly in Case B, where a proportion of contractors delivered logs, the number of available options was significantly higher than for those delivering only wood chips. However, operational alternatives such as diverting trucks to depots, performing maintenance were partially available to many of the transporters.

SUPPLY CHAIN FLEXIBILITY was affected by MISALIGNED INCENTIVES. Chipping, harvest and haulage contractors are remunerated based on the number of tons delivered to the terminals in all cases. Therefore, their level of operational flexibility depends also on their ability to forego revenue should they decide to divert trucks or perform maintenance works.

5.3.3.1.5 Performance Expectations

The performance expectation in terms of truck turnaround times at the terminal also emerged during the workshops, particularly in Case B. Carter's account during one of the workshops reveals his perspective on the expected performance at the terminal:

> **Carter (Harvest and Haulage Contractor/Case B):** "*We're getting paid to do a job, get logs delivered to a destination. What happens on your side, to get the logs chipped is your organisation, it's not for our organisation. We just expect an average time that is doable.* […] *2 years ago, we were averaging 45 minutes. We work on a 45. If we can be 45, we can make things work and that's what we budget on.*"

Interestingly, Carter's story reveals that the performance expectation was constructed based on previous truck turnaround times. However, it is unclear from his account whether the 45-minute average is considered at the centre of the truck turnaround times distributions with variation accounted for lower and higher occurrences, or if the 45-minutes act as a maximum threshold.

The next section explores the core category CONGESTION IMPACTS AND CONSEQUENCES.

5.3.3.2 Congestion impacts and consequences

The CONGESTION IMPACTS AND CONSEQUENCES core category refers to aspects of congestion that had an influence on individuals, organisations or the supply chain as a whole. There were four axial codes associated with this core category: *INCREASED COSTS*, *FRUSTRATION*, *UNCERTAINTY* and *COMPETITIVENESS.*

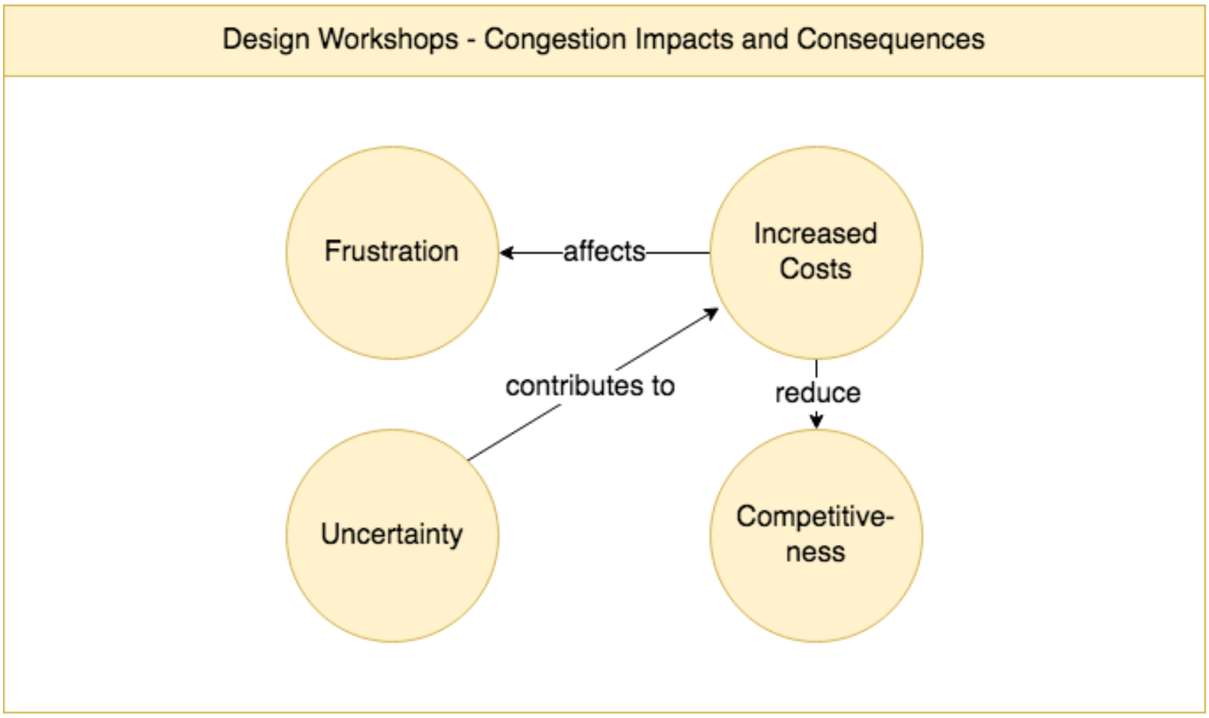


Figure 49 Stage 2: Design Workshops - Congestion Impacts Axial Codes

Figure 49 illustrates the axial codes and their relationships emerging during Stage 2: Design Workshops within the CONGESTION IMPACTS AND CONSEQUENCES core category.

5.3.3.2.1 Increased Costs

The majority of the participants mentioned increased costs as a main consequence of congestion. Ian's brief account is illustrative of cost impact that congestion entailed on the stakeholders:

> **Ian (Forestry Company/Case A):** "*Grave concerns about the cost structure at Burnie, I think it's rapidly becoming death by 1,000 cuts*."

Importantly, Ian's account also highlights the repetitive aspect of congestion which is causing cost increases on a consistent basis.

5.3.3.2.2 Frustration

Frustration also emerged frequently as a congestion consequence. Frustration was most often directly expressed in Case A but surfaced in the other cases as well.

> **Bobby (Transporter/Case A):** "*Congestion is our biggest issue. I find it very frustrating because I come off a job* […] *where I had 27 and we used to put 110 tons of ore on the ground in 2.5 minutes and now we're taking up to an hour to get rid of 40 tons. So, it's very frustrating for me to get the trucks in. Our cycle time is 90 minutes per truck, so every 90 minutes that truck should be back with another load. Those trucks are doing 5 loads, sometimes 6 instead of doing 8 loads in a shift. And because we're working around the clock, and we're paying blokes to sit in trucks, we don't wanna be paying them to sit on the wharf, we want them up getting loaded and getting back. So, it's all very frustrating for me but it's also very frustrating for the drivers.*"

Bobby's story is the most illustrative of frustration, also because he voices his frustration four times in the space of four phrases. He appears to be baffled by the lack of operational and technical complexity of the wood chip transport task, which is experiencing delays, and importantly, increased costs. It is likely that one of the reasons for the appearance of frustration was also the lack of perceived courses of action to change the situation from his perspective.

Whilst initially, the forestry companies' and transporters' representatives initially aimed their frustration towards the terminal operator, this 'us versus them' attitude seemed to reduce once all the stakeholders had spoken and presented their points of views. One potential reason for that was because of the realisation that in fact the consequences of congestion were affecting all of them in different ways.

FRUSTRATION is affected by INCREASED COSTS. Bobby's account also reveals that frustration is also affected by the fact that costs are increased, in this case by paying drivers while waiting.

5.3.3.2.3 Uncertainty

Uncertainty emerged during the workshops as an impact of congestion. Uncertainty was mentioned by relatively few participants. In Michael's case, he accounts his experience as a driver when dealing with congestion:

> **Michael (Chipping & Haulage Contractor/Case C):** "*From our point of view is harder to manage that* [congestion]*, it's an unexpected delay.*"

Thus, the uncertainty generated by unexpected waiting times and congestion at the terminal complicates the management of daily tasks from the drivers' perspective.

5.3.3.2.4 Competitiveness

The impact of congestion on competitiveness was also evidenced in several accounts, the majority of which in Case A. In Charles' account, competitiveness related primarily to the competitiveness of the terminal facility with respect to other options:

> **Charles (Forestry Company/Case A):** "*The resource is relatively limited and is what it is. What we don't understand is where that resource is going to go, what direction we're going to put that resource. The more expensive it is to put it through [the terminal], the more likely it is it's gonna go somewhere else.*"

The next section explores the core category the ROLE OF INFORMATION SYSTEMS.

5.3.3.3 Role of Information Systems

The ROLE OF INFORMATION SYSTEMS core category refers to aspects pertaining to information technology and information sharing in organisations and across the supply chain. Figure 50 illustrates the axial codes and their relationships emerging during Stage 2: Design Workshops within the ROLE OF INFORMATION SYSTEMS core category.

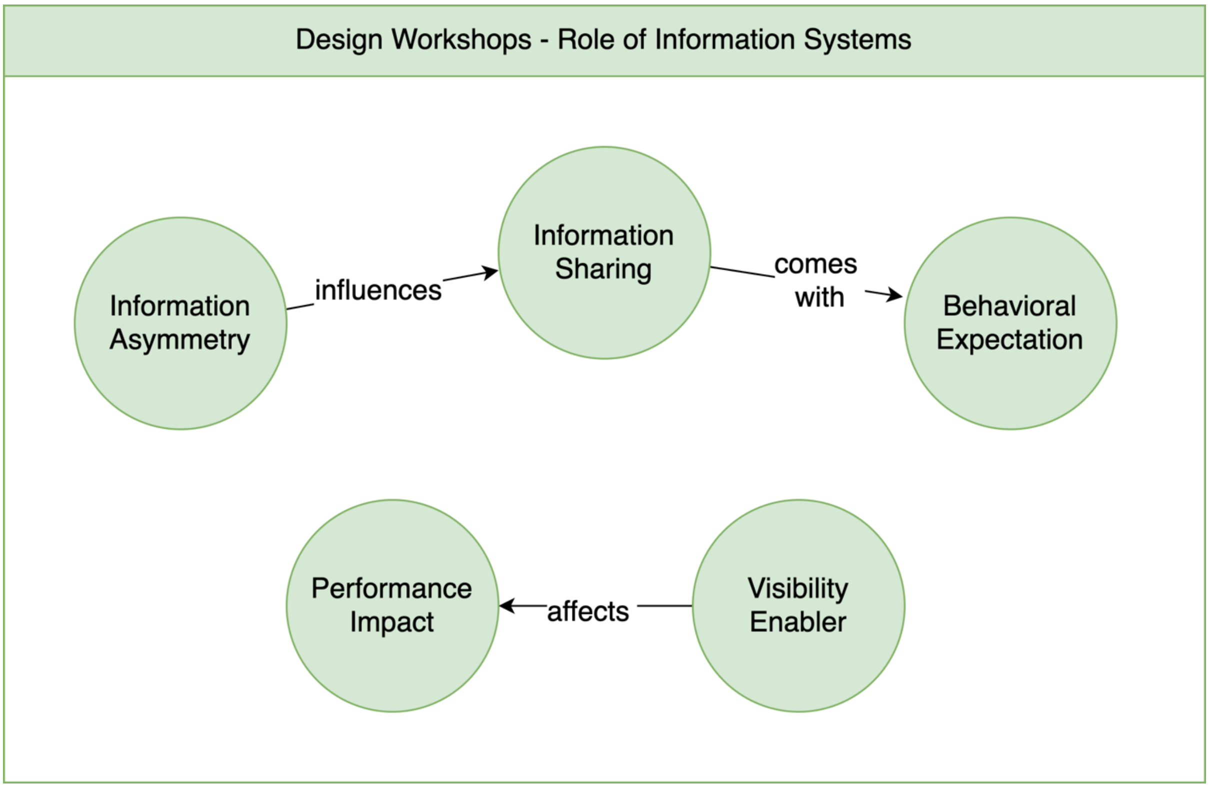


Figure 50 Stage 2: Design Workshops - Role of Information Systems Axial Codes

There were five axial codes associated with this core category: *INFORMATION SHARING, INFORMATION ASYMMETRY, BEHAVIOURAL EXPECTATIONS, PERFORMANCE IMPACT* and *VISIBILITY ENABLER*.

5.3.3.3.1 Information Sharing

Information sharing was one axial code that emerged most frequently during the workshops across the three case studies, and particularly in Case A. Information sharing was discussed primarily as a group activity in comparison to the dyadic information sharing which already took place formally or informally between sets of stakeholders. Although information sharing in a group setting, which included multiple members of the supply chain, was desirable, the participants mentioned some challenges encountered in previous attempts. The exchange between three of the participants in Case A is illustrative of one of the challenges encountered:

> **Elliott (Forestry Company/Case A):** "*I remember that we did, this was only 2-3 years ago, there was a proposal that was everyone sat around and we all agreed that we were gonna meet monthly and* [the terminal operator] *was gonna chair it and run it, and it was just operational and we were gonna talk about shut-downs and volumes and vessel times* [...] *and it did happen a few times and then it sort of fell over.*"
> **Frank (Terminal Operator/Case A):** "*Why do you think it fell over? Was it because people weren't getting anything out of it, was it because people weren't turning up, was it because people weren't getting anything, people were turning up expecting to get information but it was all one way from one party or was it because [the terminal operator] weren't organising it?*"
> **Alex (Terminal Operator/Case A):** "*I think it was more along the lines that some of the people who were at those gatherings, weren't able to commit every single time to it.*"
> **Elliott:** *"My take-away from it was that* [the terminal operator] *stopped scheduling them because they turned into bitch-sessions and the chairman wasn't in charge of the meeting and rather than saying 'tell you what, if you're complaining about something take it up with me after the meeting, we're now talking about when's your next vessel, what sort of volume are we delivering'."*

The central issue that emerged, which was echoed in the other cases, was a focus on issues, complaints and blaming, particularly in group environments, and less emphasis on identifying ways of resolving issues. Consequently, the perceived usefulness of information sharing in group settings was relatively low.

INFORMATION SHARING was also linked with *BEHAVIOURAL EXPECTATION*. Following information sharing some participants expressed the expectation that the receiver instantiates certain behaviours.

5.3.3.3.2 Information Asymmetry

Information asymmetry was also frequently mentioned by participants and emerged during the axial coding process. Two important aspects of information asymmetry can be distinguished: understanding availability and information completeness.

Understanding availability can refer to the knowledge that certain pieces of information are being collected and can be potentially shared. Participants described their information sharing efforts and the limitations of their efforts. Other participants could also react to the information sharing stories and provide suggestions for obtaining the information or even the information itself. The exchange between the two participants in Case A regarding forest resource forecasting is illustrative of such situations.

> **Frank (Terminal Operator/Case A):** "*We've done our own analysis to see what we think the resource is and where's the peak. But what we don't know is what the modelling of each company* […] *where they're filling holes along the path because there was a period of 5 years where there were no trees planted. So, are we just pushing for a 3-year period and then we drop off?*"
> **Elliott (Forestry Company/Case A):** "*Have you asked for that information?*"
> **Frank (Terminal Operator/Case A):** "*I suppose we're starting to have those discussions.*"

It appeared likely from this exchange that the information required by the terminal operator was in fact available in various organisations. However, this was not necessarily clear to the terminal operator staff.

Understanding availability can also refer to protected information which could not be shared due to legal or competitive concerns. During the workshops, several participants raised concerns regarding the possibility of sharing certain information. However, in other cases, as illustrated below, participants also understood that the importance or usefulness of certain pieces of information could be increased through sharing.

> **Ian (Forestry Company/Case A):** "*We've agreed* [ref. to internal discussions] *to make the logistical information non-competitive so, clear there is some risk because customers are going to this particular port, but I think given the benefit we'd consider doing exactly the same. We'll just declare it, we're not going to talk about* [inaudible]*, we're just going to talk about volumes and flows* [operational]*, give it a go.*"

Ian's account highlights the expectation that, whilst the information may hold some value from a competitiveness perspective, making such information available to other stakeholders may yield more benefits. Importantly, this discussion refers to reducing information asymmetry for all parties involved by pooling the available information.

INFORMATION ASYMMETRY affected *INFORMATION SHARING*.

Information completeness was also frequently mentioned. Most participants representing forestry companies, processors or transporters, highlighted that the data and information accessible to them are generally those relating to their own operations. At the same time, the participants recognised that their companies operate in conjunction with others. The perception of incomplete information was shared across participants and appeared to limit their willingness to share information.

5.3.3.3.3 Behavioural Expectation

Behavioural expectations were also mentioned by some participants, primarily in Cases B and C. Behavioural expectations primarily referred to the provision of feedback following information sharing. The expectation of feedback provision was also captured in Stage 1:

Exploration of the research (see Section 5.2.1.3.5) where it was noted that it was unclear whether this expectation was shared with the recipients of information. Beatrice's account illustrates the expectation of feedback and subsequent frustration because the expectation is not met. Importantly, the group setting in which this is done means that this expectation is now being directly expressed.

> **Beatrice (Terminal Operator/Case B):** "*I feel like I send multiple e-mails about stuff and nothing gets done* […] *the frustration is that I don't know how to get the information out so that there is a change in behaviour. I can send all the emails in the sun, but I feel like, because I'm the contact between you guys and the guys down the back. I feel like, because these guys will tell me something, I can put thousand emails out* […] *there's no change in behaviour by giving you that information.* […] *The information I'm trying to send out to you doesn't get any further.*"

Beatrice's account also highlights that there is some expectation of a change in the behaviour of the recipients. Although the expected change in behaviour was expressed, this was not subsequently defined throughout the workshops.

5.3.3.3.4 Performance Impact

Performance impact emerged as an axial code, primarily in Cases B and C. Performance gains were associated primarily with the introduction of novel digital technologies. In both cases, the digital tool discussed most frequently was eDockets, a tool that integrates truck geo-positioning with weigh-bridge records. The terminal operator in Case B was interested in procuring an eDockets system. The terminal operator in Case C had already started the procurement process for an eDocket system. In both cases, multiple participants expressed their expectation that the introduction of eDockets in particular would lead to performance improvements. David's short quote is illustrative of this expectation:

> **David (Chipping and Haulage/Case B):** [referring to eDockets] "*It's a no-brainer*."

At the same time, however, other participants expressed a degree of caution regarding the potential impact of eDockets. Kevin's account regarding previous implementations of eDockets in other supply chains in which his company is active is illustrative of the potential challenges posed by such digital tools:

> **Kevin (Transporter/Case C):** "*The introduction of the eDockets, it needs to be introduced properly* […] *We've been in 3 areas actually where* [inaudible] *from a transport hauler we don't get too much information.*"

Kevin's comment was further supported by Anthony who highlighted that new technologies may in fact duplicate work or create more work for the organisation's staff.

> **Anthony (Terminal Operator/Case C):** "*I've seen people fall in that trap all the time. Oh, we get this new technology, we do this or that, but it ends up creating more work, or it duplicates what you already had and it's no better*"

The potential impact on performance of new digital tools was recognised as both positive and negative. Nonetheless an expectation of performance gains appeared to be prevailing across the participants.

5.3.3.3.5 Visibility Enabler

Visibility enabler was another axial code emerging during the coding process. Visibility enabler referred almost exclusively to digital tools and was mentioned primarily in Case B and C by some of the participants. The key dimension of visibility was that of breadth. Arthur's comment is illustrative of the visibility enabler role:

> **Arthur (Terminal Operator/Cases B):** [talking about the proposal for implementing eDockets] "*complete visibility of the supply chain* […] *basically creating a platform for all your GPS data to become integrated.*"

One aspect of the breadth of visibility is for whom the breadth is expected to be improved. In Cases B and C, several participants were vocal about the improved visibility digital tools may offer, particularly when referring to eDockets. However, it was not clear whether all stakeholders would benefit from a similar improvement in visibility.

VISIBILITY ENABLER was strongly related to *PERFORMANCE IMPACT*. Interestingly, performance improvements were primarily discussed in relation to digital technology that enabled improved operational visibility.

5.3.4 Relationships Between Core Categories

The CONGESTION FACTORS core category refers to aspects of terminal and supply chain operations that are conducive to the appearance of congestion. There were five axial codes associated with this core category: *INTERDEPENDENCE OF OPERATIONS*, *LIMITED COORDINATION*, MISALIGNED INCENTIVES, *SUPPLY CHAIN INFLEXIBILITY* and *PERFORMANCE EXPECTATIONS.*

The CONGESTION IMPACTS AND CONSEQUENCES core category refers to aspects of congestion that had an influence on individuals, organisations or the supply chain as a whole. There were four axial codes associated with this core category: *INCREASED COSTS*, *FRUSTRATION*, *UNCERTAINTY* and *COMPETITIVENESS.*

The ROLE OF INFORMATION SYSTEMS core category refers to aspects pertaining to information technology and information sharing in organisations and across the supply chain. There were five axial codes associated with this core category: *INFORMATION SHARING, INFORMATION ASYMMETRY, BEHAVIOURAL EXPECTATIONS, PERFORMANCE IMPACT* and *VISIBILITY ENABLER.*

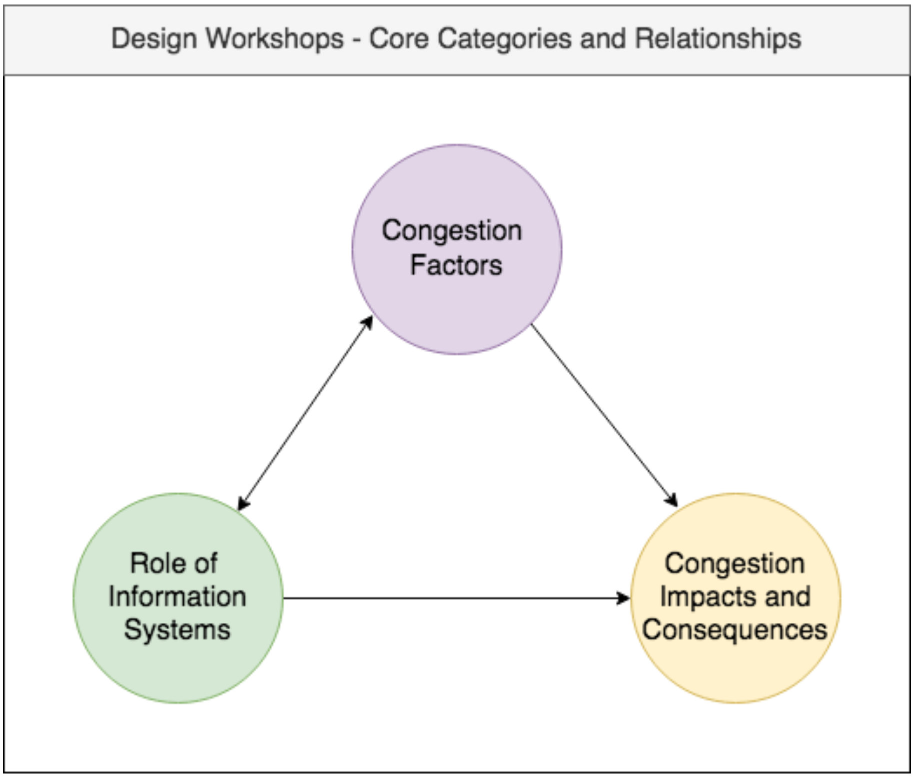


Figure 51 Stage 2: Design Workshops - Core Categories and Relationships

The relationships between the three core categories are illustrated in Figure 51.

CONGESTION FACTORS affected CONGESTION IMPACTS AND CONSEQUENCES. This was primarily due to *SUPPLY CHAIN COORDINATION*, *INTERDEPENDENCE OF OPERATIONS* and *SUPPLY CHAIN FLEXIBILITY* which influenced the extent of the congestion impacts and consequences. CONGESITON FACTORS also affected the ROLE OF INFORMATION SYSTEMS. This was mainly through *LIMITED COORDINATION*, *INTERDEPENDENCE OF OPERATIONS* which affected the need for communication, and improved operational visibility and control.

The ROLE OF INFORMATION SYSTEMS affected CONGESTION FACTORS. This was through *INFORMATION SHARING* and *VISIBILITY ENABLER* These aspects of information systems affected the extent to which congestion factors occurred in the operations. The ROLE OF INFORMATION SYSTEMS also affected CONGESTION IMPACTS AND CONSEQUENCES. This was primarily through *VISIBILITY ENABLER*.

The next section discusses the preliminary results gained from this stage.

5.3.5 Stage 2 Preliminary Results and Interpretation

The preliminary results obtained during Stage 2: Design Workshops through the iterative process explained in Section 4.7 were:

WR-1. *Congestion is an emergent property of supply chains.* Most congestion factors discussed during the workshops pertained to the supply chain such as interdependence of operations (Section 5.3.3.1.1), limited coordination (Section 5.3.3.1.2), incentive misalignment (Section 5.3.3.1.3) and supply chain flexibility (Section 5.3.3.1.4).

Several participants in Cases A and B mentioned terminal infrastructure requirements, however these were not the central points of the workshops. James' statement during the workshop in Case C encapsulated the idea that several congestion factors pertained to the supply chain "*This is not a port congestion issue; this is a harvesting issue that's manifesting in haulage.".* Few other participants clearly expressed the link between congestion and supply chain factors. It is likely that participants in Case C recognised the impact of the supply chain operations on port congestion given their high exposure the challenges in the supply chains which affected transportation. These included harvesting restrictions leading to truck arrivals within a restricted timeframe and decreases in wood chip quality tolerances leading to unloading delays due to re-chipping. However, the information sharing mechanisms implemented in Case A, which involve the supply chain stakeholders, suggest that this perspective permeated in other cases as well. This insight strengthened the researcher's belief that congestion is in fact an emergent property of the supply chains which requires the involvement of the supply chain stakeholders for identifying mutually acceptable outcomes.

WR-2. *Misaligned incentives across and along the supply chain contributed to the appearance of congestion.* This insight builds on evidence from workshops (Section 5.3.3.1.3) and strengthens the preliminary insight from Stage 1: Exploration (ER-5, p.131). It was interesting however that incentive misalignment appeared not only in a fragmented supply chain setting, such as the one in Case A where a certain degree of incentive misalignment was expected given the results during Stage 1: Exploration (Section 5.2.1.1.5). Incentive misalignment also appeared in Cases B and C in which the terminal operators were the principals of significant proportions of the chipping, harvest or haulage contractors. This setup ostensibly provided the terminal operators with sufficient power to influence the contractors' behaviours through the redesign of more aligned incentives.

The effects of misaligned incentives regularly reappeared in most cases. It was not entirely clear to the researcher why misaligned incentives persisted in the three cases. It is possible that the organisational or supply chain fragmentation would play a role in the lack action towards a better alignment of incentives. In all cases, the transporters were typically subcontractors to other organisations and therefore twice removed contractually from the principal. It is also possible that the relatively inequal distribution of congestion costs between the terminal operator and contractors had led to limited action towards a better alignment of incentives.

WR-3. *Increasing supply chain flexibility could help mitigate congestion.* This insight arose following the workshops (Section 5.3.3.1.4) and was strengthened by results in Stage 1: Exploration (Section 5.2.1.1.6). Both upstream and downstream flexibility could help alleviate congestion: alternative delivery options for wood chips could limit the number of trucks arriving at a terminal during the day, diversifying the production sites could also spread truck arrivals over a larger period of time and avoid production restrictions. Organisational incentives and regulatory restrictions can affect however the level of supply chain flexibility.

WR-4. *Specifying poorly defined congestion metrics in contractual agreements can lead to unintended consequences*. Performance expectations with regards to congestion were mentioned only in Case B (Section 5.3.3.1.5). However, this occurrence was considered critical by the researcher as it complemented occurrences in Cases A and C from Stage 1: Exploration (Section 5.2.1.1.7) and it allowed the researcher to gain additional insights on the participants' conceptualisation of congestion. It became apparent to the researcher that two concurrent factors potentially misconstrued the participants' performance expectations: a perception of the average levels of congestion as the maximum acceptable threshold and a fixation on the threshold which limited the participants' interest in understanding the reasons and their contribution to the appearance of congestion.

WR-5. *The average truck turnaround time used in isolation from other indicators and statistical measures may misrepresent congestion.* A large proportion of the truck turnaround times were in fact smaller than the average (Section 5.3.1.2). However, the variability of truck turnaround times was generally large, and usually biased towards high values. The analysis of truck arrival frequency highlighted that frequent truck arrivals can be an important cause of congestion (see Section 5.3.1.3). In all cases, the inter-arrival time distribution was right skewed with a large proportion of arrivals in less than 5 minutes from one another. The simulation model scenario analysis highlighted the impact frequent arrivals had on truck turnaround, waiting times, turnaround time reliability and truck engine idling emissions (see Section 5.3.2.1). The analysis of truck geo-positioning data revealed that the terminal equipment was generally operating in a consistent manner and did not significantly impede operations (see Section 5.3.1.1). Furthermore, simulation modelling scenario analysis highlighted that additional infrastructure or higher capacity trucks could have an impact on waiting times. Automation technology could reduce truck turnaround times averages but had limited impact on truck waiting times and consequently congestion (see Section 5.3.2.1). The largest and most robust expected benefits could be obtained through the use of a terminal appointment system. Consequently, coordination mechanisms were a significant focus of the workshops.

WR-6. *The participants' expectations of performance improvement as a result of digital tools implementations were not always grounded in evidence.* These expectations persisted even when accounts of experiences with similar digital tools in other context contradicted their expectations. The participants' expectations for performance improvements were mainly discussed in Cases B and C (Section 5.3.3.3.4). This insight was corroborated by the results in Stage 1: Exploration (Sections 5.2.1.3.7 and 5.2.1.3.8). Performance improvement expectations were almost exclusively linked to the implementation of new digital tools.

Interestingly, in Cases B and C, the discussions centred on the same digital tool, an eDocket system. These expectations appeared to stem from a belief that enhanced visibility and particularly data timeliness would lead to performance improvements. Several participants in Case C, including some representing the terminal operator which was leading the implementation of the eDocket digital tool expressed concerns regarding the limited or even potential negative effects on performance such tools have had in other situations. Nonetheless, such accounts did not appear to influence the participants' beliefs of the performance improvements as a result of new digital tools implementations. In both cases, the participants' arguments regarding the potential benefits of the digital tools were similar. This strengthened the researcher's suspicion that the performance improvement expectations were instilled by external parties. This situation also led the researcher to suspect that there was a low level of clarity amongst participants on the mechanism through which digital tools could or would influence supply chain operations and lead to performance improvements.

WR-7. *Lowering information asymmetry contributed to the initiation of information sharing between participants.* It was suspected following Stage 1: Exploration that information asymmetry in the shape of confidential information or lack of knowledge regarding others' available information was a factor impeding information sharing (see ER-9, p.132). Stage 2: Design Workshops provided additional evidence in this regard (Section 5.3.3.3.2). Interestingly, the workshops provided an outlet for reducing information asymmetry between the participants. This outlet was particularly explored by the participants in Case A. The outcomes the workshops in Case A (Section 5.4.2) are considered to be partially achieved as a result of the reduction in information asymmetry between the participants in regards to confidentiality and information availability for sharing with others.

WR-8. *The effectiveness and continuity of new or existing information sharing mechanisms is partially dependent on appropriate associated behavioural responses of recipients.* The researcher suspected that many participants had behavioural expectations associated to information sharing which were not necessarily known to the information recipients (see ER-10, p.133). This suspicion was supported during one of the workshops: "*I feel like I send multiple e-mails about stuff and nothing gets done…" Beatrice (Terminal Operator/Case B).* It is highly likely that information sharing without the expected behavioural response from the information recipients will eventually lead to some level of frustration and potentially a reduction of information sharing. Similarly, sharing information without a clear understanding of what the information would be useful for may fail to yield any tangible outcome for two reasons: the information may be unsuitable for supporting the recipients' decision-making; the information may also be ignored. Understanding and meeting the behavioural expectations associated with information sharing may be a key factor influencing the effectiveness and continuity of new or existing information sharing mechanisms.

The next section presents the analysis of the last stage of the participatory design approach, the evaluation.

5.4 Stage 3: Evaluation[12]

The Stage 3: Evaluation semi-structured interviews were conducted 3-6 months following the last scheduled design workshop in each case study. The participants that were involved in Stage 1: Exploration and Stage 2: Design Workshops were targeted for the Stage 3: Evaluation interviews. 11 participants were interviewed: 5 out of 6 participants involved in previous stages participated in this stage for Case A; 2 out of 4 participants involved in previous stages participated in this stage for Case B and 3 out of 4 participants involved in previous stages participated in this stage for Case C. One additional participant was interviewed in Case C, James. Although the respondent did not participate in Stage 1: Exploration directly, he was interviewed due to the extensive knowledge and understanding of the supply chain displayed during the workshops. It was not clear from the onset whether the designs emerging from the workshops would be implemented. However, since that happened and quantitative data were available, the impact of the implemented designs was also evaluated.

Where mitigation mechanisms were implemented, these were evaluated using exploratory data analysis and statistical testing for differences between distributions (see Section 4.6.3.2).

5.4.1 Participatory Design Approach Effectiveness

The workshops led to the emergence of several mechanisms aimed at mitigating congestion or congestion factors. The majority of these mechanisms were designed and implemented by stakeholders in Case A.

In Case A, the emerging mechanisms were primarily centred on information sharing and coordination. Thus, stakeholders agreed to share truck and vessel scheduling information and to provide regular and standardised feedback to one-another with regards to vessel loading performance. Furthermore, some stakeholders expressed interest and support in the implementation of a terminal appointment system to facilitate truck coordination.

i. The stakeholders agreed to **share truck scheduling information** in the form of weekly meetings where the forestry companies, transporters and terminal operators would participate and share insights. Stakeholders also agreed to **share vessel scheduling information** to attempt to reduce clashes in vessel arrivals and subsequent costs. Charles' intervention during one of the workshops highlights the proposal to the other forestry companies' representatives to share information jointly.

    Charles (Forestry Company/Case A): "*How about you and me kick it back off. I meet with* X *every Monday, I have an agenda, in it has been how we get this going again, and*

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[12] This section draws from Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P. "*Using Discrete-Event Simulation to Compare Congestion Management Approaches at a Port Terminal.*" Simulation Modelling Practice and Theory Journal, UNDER REVIEW

Neagoe, M., Hvolby H-H., Taskhiri, M. S., Nguyen, H.-O. and Turner, P "What's the hold up? A participatory design approach to understanding and ameliorating congestion at an Australian marine terminal." Maritime Economics and Logistics, UNDER REVIEW *sharing information, especially on shipping, cuz I don't know when your vessels are, you don't know when mine. I'm happy to push that back off.*"

Two forums for information sharing were in fact established by the participants: one operational forum which included representatives of the terminal operator, wood processors and transporters which was concerned with landside logistics issues including truck scheduling and landside congestion management. The second tactical and strategic forum included the terminal operator and the forestry companies in which issues relating to vessel scheduling, vessel loading, inventory management and strategic improvements.

ii. The terminal operator requested **regular and standardised feedback** from the forestry companies with respect to the vessel loading performance, primarily compaction which is a performance metric measured by the final customers, the pulp manufacturers. Whilst this initiative was not directly linked to landside congestion management, it does reveal the terminal operator interest for the competitiveness of the customers' supply chains.

Frank (Terminal Operator/Case A): "*We're trying to track our compaction factors and index. One way you can do the compaction index is if you have a dry matter percentage and also the basic density. Sometimes we get the dry matter percentage, sometimes we get the basic density, but it's sort of irregular. So, what I was promoting was that should we put it all in a single document so that at the end of each vessel loading we've got a single sheet that has all the relevant information. So that if we ever want to look back at data we can go and look back in a spreadsheet.*"

iii. An unexpected outcome of the workshops was one of the forestry companies' **interest in the implementation of a terminal appointment system** following an experience where only one company used the terminal and seeing significantly reduce turnaround times for their own trucks, as Elliott's account shows:

Elliott (Forestry Company/Case A): "*Where are we at with the terminal appointment system that you mentioned? Because everyone on our side saw that 14-minute drop and went if we can grab 2/3 of that from a TAS* [...] *all of sudden our guys will rather more interested in a TAS rather than going 'ah shit' which was some of their reactions.*"

It is possible that the stakeholders' realisation that at least some of the truck turnaround times reduction generated in the simulation modelling through improved coordination and the use of an appointment system was in fact achievable in real-life situations as well.

In all cases, the workshops appeared to positively influence the understanding of the participants with respect to their role in the supply chain and potential role in mitigation congestion. This understanding is evidenced in the participants' willingness to continue further interactions as highlighted by Charles' and Anthony's accounts:

Charles (Forestry Company/Case A): "*That collective approach where we helped each other, I guess* [the terminal operator] *facilitated that. That wouldn't have happened if we* *all wouldn't have been in the same room and talking so, that's a testament to what we're achieving.*"

Anthony (Terminal Operator/Case C): "*I Don't want you guys to walk out of here thinking that was a nice talk fest. That's not the intention. The intention today is to show where they got to in the study and for us to have an open and honest discussion about what the challenges are [...] I don't see this as the end of it at all. There's no clear answer to you today, we know there's a lot of challenges in front of us. But we're gonna continue to work on this and we're gonna continue to communicate with you. Because from what I see, I can see we can just get benefits from just improving our communications.*"

The participants in Case B agreed to hold a subsequent design workshop to pick up on the threads developed in the first workshops. This workshop was planned to take place approximately 3 months after the first workshop in the case study. The workshop was however cancelled just prior the start date.

Interestingly, in Case A, where the simulation model was developed and extensively discussed with stakeholders, the comments made by some of the participants on the simulation model results were also revealing of their understanding of the situation and the potential impact different congestion mitigation approaches may have:

Frank (Terminal Operator): *"I'm surprised to see how little impact things like the two ramps* [upgrade] *the same, the 40-ton trucks. It's interesting once you do model it, some of the sections you have in your mind, you think may fix a problem, where you could invest* […] *and at the end of the day it still hasn't made a massive difference. It's interesting, your perception versus what this modelling is suggesting"*

The simulation model results also generated discussions on the degree of collaboration required between participants. These discussions incentivised the researcher to extend the initial simulation model and investigate the impact of user behaviours and system parameters (see Section 5.3.2.2). The results from the extended simulation model were subsequently discussed with primarily terminal operator.

The evaluation semi-structured interviews in Case A revealed differences in perceptions regarding congestion and mitigation mechanisms for some of the interviewees, while others maintained the idea that limited change has taken place. In terms of perceived changes, 2 respondents praised in particular the information sharing meetings as useful tools to discuss problems, share ideas and improve information flows amongst stakeholders. The other 3 respondents stated that no major changes had taken place with regards to congestion and its management. However, even when maintaining that little has changed, the 3 respondents mentioned that people are talking more and that information sharing with regards to vessel arrivals did have some effect on the number of schedule clashes. The coordination dimension, particularly from the terminal operator side emerged during the evaluation as well: One of the perceived challenges with the workshop approach was considered the lack of enthusiasm and leadership from the terminal operators' side. One respondent suggested that many of the issues could be resolved by the terminal operator.

Stage 3: Evaluation was planned as a one-off engagement. However, the researcher had the opportunity to maintain contact with several participants in Case A. This allowed the researcher to gain additional insights pointing towards the fact that the participatory design was an iterative process that some participants had internalised and subsequently reapplied.

More than a year after the completion of Case A, in an informal discussion with one representative of the terminal operator, Alex, the terminal manager the researcher was informed that Alex had been assigned to manage another bulk cargo marine terminal for log exports. The terminal was also experiencing issues with landside congestion and similar levels of tension and frustration between supply chains stakeholders as in Case A. Alex mentioned that he approached congestion first by exploring its causes and finding that most complaints related to the morning peaks prior to the opening times of the facility (similar to the situation in Case B). Alex's response was to initiate communication with the haulage contractors and the forestry companies to better understand why this was occurring and identify potential mitigation mechanisms. This response resembled the participatory design approach adopted in this research with participants in Case A.

Furthermore, the researcher was involved in a project exploring the potential advantages and disadvantages for implementing a terminal appointment system at the Case A terminal. At the time of writing of this research, this process was underway albeit with limited input from the researchers. Nonetheless, these discussions had led to changes in the contractual arrangements between stakeholders in Case A. Contractual arrangements were adapted to specify the average number of trucks expected per hour from each customer. This change was also catalysed by the coordination mechanism experiment ran by the participants, which will be discussed next.

In Cases B and C, Stage 3: Evaluation revealed significant differences in congestion at the terminal primarily due to a decline in the market price and the outbreak of the COVID-19 pandemic. As a result, wood chip production decreased by almost half and truck turnaround times had also decreased. Since November 2019, the chipping and haulage contractors were working on production quotas, to ensure equipment utilisation across contractors but limit production. However, because of the severe market downturn, any implementation of congestion mitigation approaches discussed during the workshops was put on hold. In terms of the understanding of landside congestion, the majority of respondents suggested that they already had a relatively solid prior understanding of congestion and the factors contributing to its appearance.

In Case C, during the participatory design, the terminal operator pursued the implementation of two technology tools: an optical character recognition (OCR) camera system to improve understanding on truck unloading and waiting time while on the terminal. The procurement process for the OCR system commenced during the participatory design process and partially catalysed by discussions with the researcher.

The next sub-section explores the impact of the congestion mitigation approaches implemented by participants.

5.4.2 Design Implementation Impact

The terminal operator in Case A trialled a coordination mechanism which consisted of a new truck unloading policy, where trucks belonging to each company would have a dedicated unloading ramp in an effort to reduce turnaround times of trucks due to overlaps between the two companies. To minimise waiting times between deliveries of different products, the stakeholders agreed to jointly employ traffic marshals.

The research team collected data over 3.5 months, between the 8th of April and 28th of July 2019. Between the 8th and 30th of April and 1st and 31st of June, trucks were unloaded in the order of arrival (*Control*). Between the 1st and 30th of May and 1st and 28th of July the coordination mechanism, consisting of the new truck unloading policy and the use of marshals, was employed.

Table 13 Case A - Pre- and Post-Implementation Descriptive Statistics

Indicator	Company 1 Turnaround Times (min) PRE	Company 1 Turnaround Times (min) POST	Company 2 Turnaround Times (min) PRE	Company 2 Turnaround Times (min) POST
Mean	26.14	23.17	26.63	21.22
Median	22.72	19.72	23.19	18.27
Mode	15.42	13.35	14.43	14.35
Standard Deviation	13.58	10.89	15.56	13.85
Variance	184.34	118.54	241.98	191.73
Range	270.88	131.15	287.37	258.50
Minimum	11.40	5.80	10.55	5.82
Maximum	282.28	136.95	297.92	264.32
Count	3239	3459	2712	2847
SW Test Result	0.74*	0.81*	0.71*	0.48*

* significant at 0.01 level indicating non-normally distributed data (Shapiro-Wilks test)

For both companies, there is a decrease in the control and experiment weeks' means of 12% and 20% for Companies 1 and 2 respectively. Similarly, the standard deviation between control and experiment weeks also decreased by 20% and 11% for Companies 1 and 2 respectively. This is noticeable also when comparing the maximum values for each company and the range of the samples. The truck turnaround data is summarised in Table 13.

Table 14 Case A - Performance Impact of Coordination Mechanism

Performance Indicators	Company 1 PRE	Company 1 POST	Company 2 PRE	Company 2 POST
Avg. TTT (min)	26.14	23.17	26.63	21.22
Avg. Wait (min) [a]	N/A	-2.97	N/A	-5.41
Rel. 25	58%	56%	70%	77%
Emissions (t CO_2) [b]	N/A	-0.72	N/A	-1.39

[a] Estimates based on the difference in average turnaround times. Exact waiting times were unavailable due to the lack of GPS data from trucks during this experiment; [b] Estimates based on the difference in average turnaround times and truck engine idling CO_2 emissions from Starcrest Consulting Group (2018)

The performance impacts of the coordination mechanism were also compared using the performance indicators developed and discussed in Section 5.3.2 and are summarised in Table 14. The decrease in average turnaround time is noticeable for both companies. The reliability marginally decreased for Company 1 by 2 percentage points but increased by 7% for Company 2. The waiting times and emission impacts are estimated from the truck turnaround times. As the terminal unloading process or infrastructure has not significantly changes, it was assumed that the differences in truck turnaround times were in fact from a reduction of waiting. Therefore, the differences between the pre- and post-coordination mechanism implementation waiting times and emissions were reported.

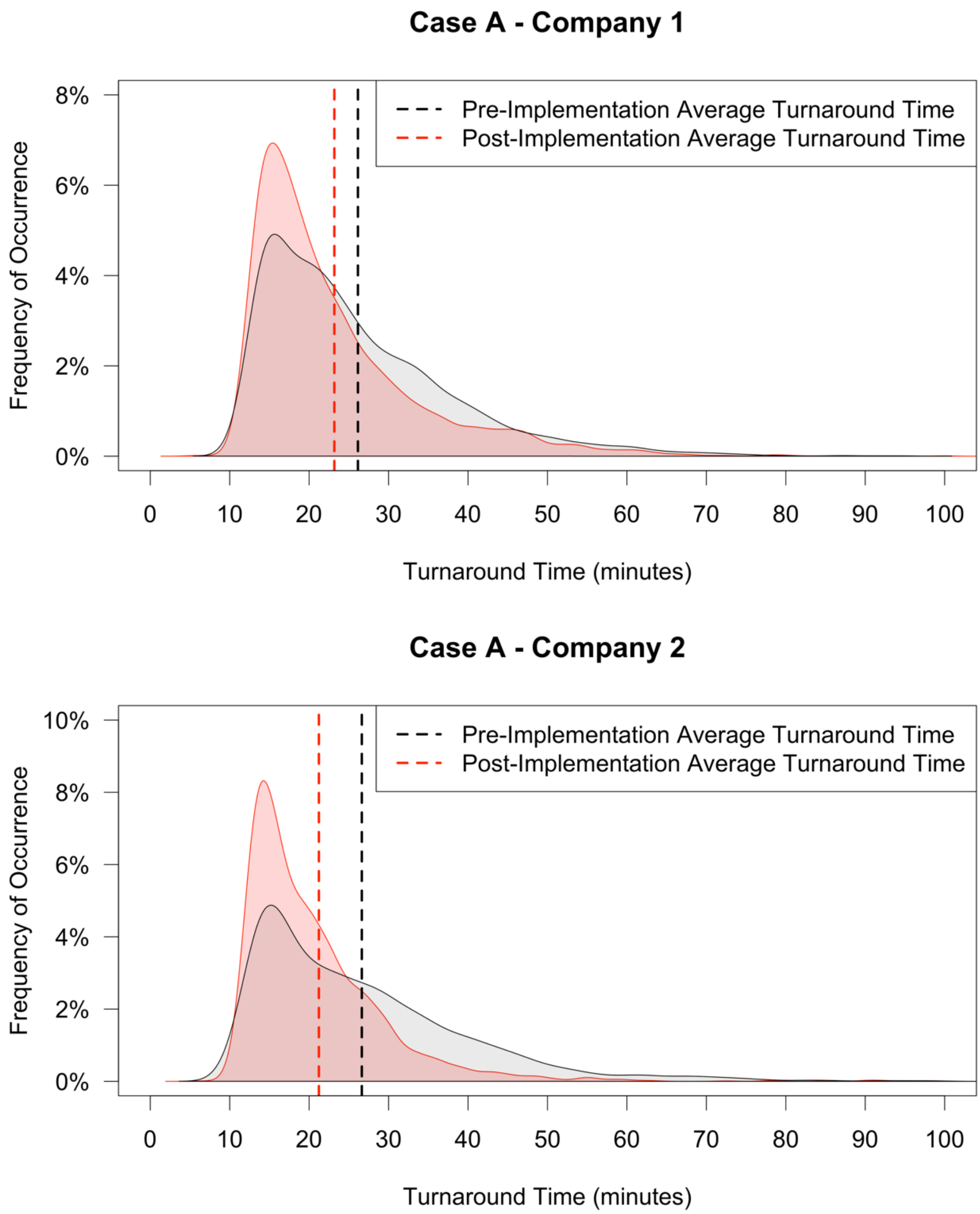

Figure 52 Case A - Coordination Mechanism Implementation Results

The differences in turnaround time variability between pre- and post-coordination mechanism implementation are highlighted in Figure 52.

The statistical significance of the differences was tested using the Mann-Whitney test given the non-normal distribution of the samples (tested using Shapiro-Wilks, results shown in Table 13). The analysis results indicate that the approach had a statistically significant impact in reducing truck turnaround times for both companies, as shown in Table 15, therefore suggesting that allocating dedicated unloading ramps for each company can help reduce turnaround times and by extension, congestion. Interestingly, discussions with terminal staff following this trial revealed that the dedicated unloading ramps helped reveal issues of internal coordination of the transport flows by minimising the interference the transporters' operations had on one-another.

Table 15 Case A - Coordination Mechanism Impact Test Results

Tests	Mann-Whitney W value	p-value
Company 1 Pre- vs Post-Turnaround Times	6,494,700	<0.01
Company 2 Pre- vs Post-Turnaround Times	4,895,700	<0.01

The next section presents the summary reflections of this chapter.

5.5 Summary Reflections

This chapter has presented the analyses of qualitative and quantitative data collected at each of the 3 stages as well as the results produced at each stage. This iterative approach has generated considerable insight into the primary research questions. The next chapter will interpret these results to identify key findings and discuss these in the context of the literature identified in Chapter 3.

The results of this research are: Many congestion factors were in fact emergent from the interplay between supply chain elements. The stakeholders in different organisations also had different perspectives on the congestion causes and suitable mitigation options. The limited coordination between supply chain stakeholders was one of the main factors that led to the appearance of congestion. Congestion affected participants, organisations and the supply chain alike in more or less visible yet impacting ways. Information systems supported daily operations of the participants. Many participants expected new digital tools to generate significant impact on the supply chain without an apparent clarity on the mechanism through which this would be achieved. Information asymmetry and behavioural expectations were two key factors contributing to the initiation and continuation of new and existing information sharing practices. Information sharing and digital tools supported the coordination mechanisms implemented by participants which led to a reduction in truck turnaround times and consequently congestion.

The next chapter presents the six key findings emerging from the interpretation of the results of the data analyses. The key findings are discussed and interpreted in the next chapter in relation to the extant research literature and the research questions.

Chapter 6 Interpretation and Discussion of Findings

6.1 Introduction

The previous chapter has presented the data analysis results.

This chapter presents the six key findings emerging from the interpretation of the results presented in the previous chapter. The approach to generate the findings from the results of this research is described in Section 4.7. The key findings are presented in relation to the primary research questions and discussed in the context of the literature. The research questions and the associated key findings are presented in Figure 53.

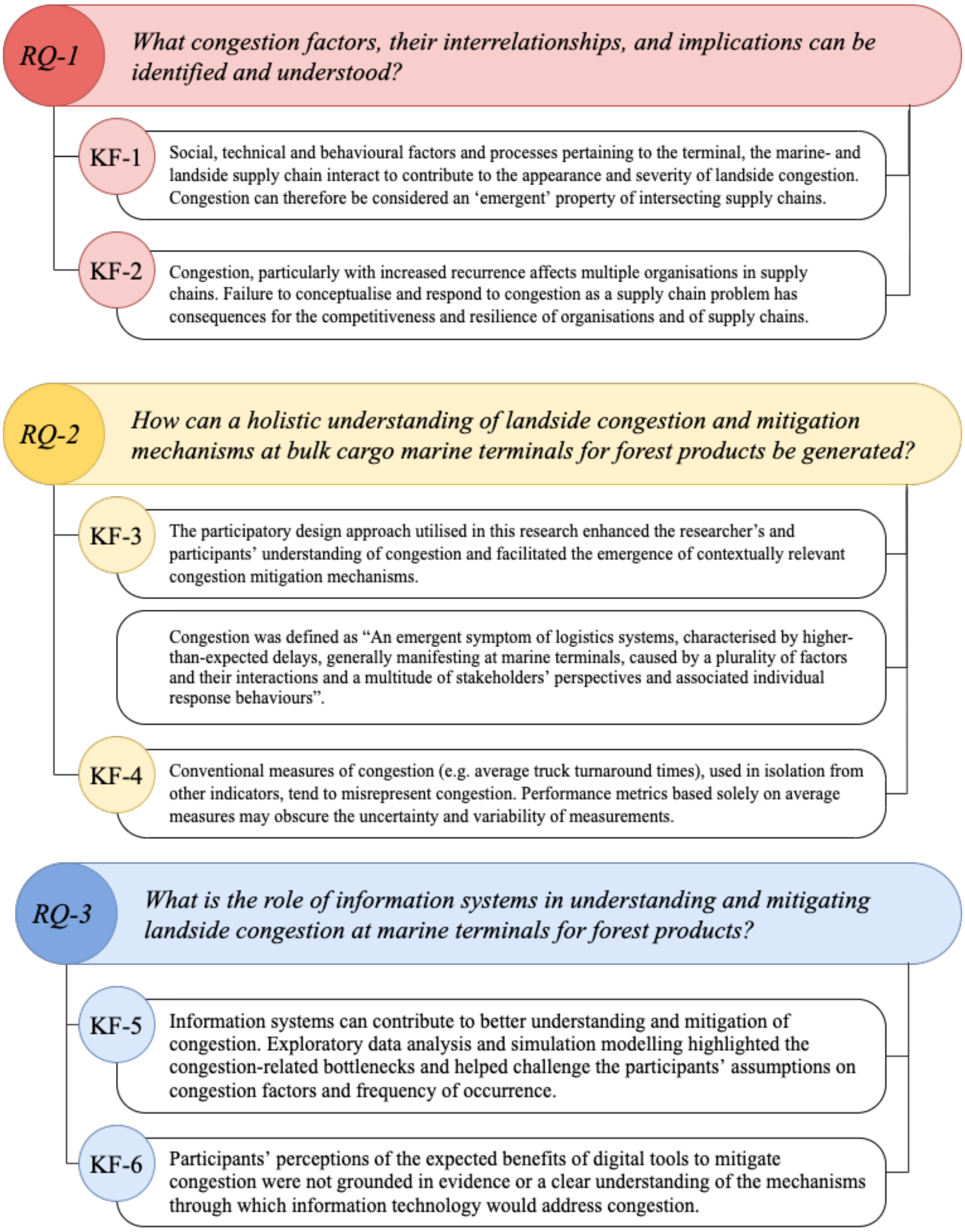

Figure 53 Research Questions and Key Findings

Within each research question, the key findings have been ordered in terms of priority as interpreted by the researcher and are discussed and interpreted in relation to the extant research literature and the main research question they pertain to. This chapter presents a new model of congestion factors and a framework for participatory mitigation of congestion that are contributions to the body of knowledge around information systems and their role in congestion.

The structure of this chapter is as follows:

- Section 6.2 provides an interpretation and discussion of the key findings (***KF-1.*** and ***KF–2.***) that primarily answer the first research question: *What congestion factors, their interrelationships, and implications can be identified and understood?* The key findings mostly associated with this research questions are:

  KF-1. Social, technical and behavioural factors and processes pertaining to the terminal, the marine- and landside supply chain interact to contribute to the appearance and severity of landside congestion. Therefore, congestion can be considered an 'emergent' property of intersecting supply chains. As a result, congestion mitigation is often perceived to fall outside individual organisations' responsibility. The factors and processes identified in this research include: limited coordination of logistics flows within organisations, and within and between forest products supply chains; misaligned incentives within organisations, and within and between forest products supply chains; excessive interdependence of operations within supply chains and technical limitations to flexibility; infrastructure capacity or performance limitations; behavioural responses associated with operational disruptions and congestion; misinterpretation of performance expectations; plurality of perspectives on congestion within and between supply chains.

  KF-2. Congestion, particularly with increased recurrence, affects the costs, compliance and fatigue risks of truck operators and creates operational uncertainty and the generation of significant frustration for participants across supply chains. Congestion is not only an operational problem. Failure to conceptualise and respond to congestion as a supply chain problem has consequences for the competitiveness and resilience of individual organisations and supply chains.

- Section 6.3 provides an interpretation and discussion of the key findings (KF-3. and KF-4.) that primarily answer the second research question: *How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?* The key findings mostly associated with this research questions are:

  KF-3. The participatory design approach utilised in this research enhanced the researcher's and participants' understanding of congestion and facilitated the emergence of contextually relevant congestion mitigation mechanisms. A key component of the participatory design approach was the interplay between the qualitative and quantitative data and analysis. Qualitative techniques permitted identifying aspects pertaining to congestion that do not easily lend themselves to quantification. Quantitative techniques allowed the validation of or challenging of participants' perceptions and beliefs underlying their conventional responses to congestion. An outcome of the approach was that the participants designed and implemented mechanisms to mitigate congestion and initiated the deployment of digital tools to support coordination efforts and also attempted to apply by themselves the same approach in other similar circumstances.

KF-4. Conventional measures for congestion (e.g. average truck turnaround times), used in isolation from other indicators, tend to misrepresent congestion. Performance metrics based solely on average measures may obscure the uncertainty and variability of measurements. Stakeholders may have unrealistic expectations as the average is often confused with the maximum. Congestion mitigation measures aimed at addressing average measures for congestion may, in fact, fail to address congestion even if successful at reducing the average measures.

- Section 6.4 provides an interpretation and discussion of the key findings (***KF-5*** and ***KF-6***) that primarily answer the third research question: *What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?* The key findings mostly associated with this research questions are:

KF-5. Information systems can contribute to better understanding and mitigation of congestion. Exploratory data analysis and simulation modelling highlighted the congestion-related bottlenecks and helped challenge the participants' assumptions on congestion factors and frequency of occurrence. Furthermore, the simulation scenario analyses helped direct the participants' attention towards designing for the most promising congestion mitigation approaches.

Information sharing supported the supply chain coordination mechanisms designed by participants. Information sharing, both at the operational and tactical levels pertaining to truck and vessel schedules, was instantiated to enhance coordination between the supply chains intersecting at the terminal. In one case study, the participants also commenced the procurement process for a terminal appointment system to facilitate truck arrivals' coordination at the terminal. The initiation of information sharing was partially contingent on addressing information asymmetry between participants and a mutual definition of each party's behavioural responses following information sharing.

KF-6. The participants' perceptions of the expected benefits of digital tools to mitigate congestion were not grounded in evidence or a clear understanding of the mechanisms through which information technology would address congestion. As a result, the way in which technology was adopted and utilised by users was rarely closely correlated to congestion mitigation. Indeed, there were numerous examples of where individual organisations had justified investment in IT tools by reference to landside congestion management but had not subsequently analysed the data produced by these systems or utilised it to address congestion-related challenges proactively.

- Section 6.5 presents the summary reflections of this chapter.

6.2 Identifying and Understanding Congestion Factors, Their Interrelationships and Implications (RQ-1)

This section provides an interpretation and discussion of the key findings (***KF-1.*** and ***KF-2.)*** that relate primarily to the first research question: *What congestion factors, their interrelationships, and implications can be identified and understood?* These findings have been ordered in terms of priority as interpreted by the researcher.

6.2.1 Social, technical and behavioural factors pertaining to the terminal, the marine- and landside supply chain interact to facilitate the appearance of landside congestion (KF-1.)

The interpretation of the analyses and results that led to this key finding can be identified as follows: Stage 1: Exploration and Stage 2: Design Workshops grounded theory-based coding presented in Sections 5.2.1.1 and 5.3.3.1. The exploratory data analysis, particularly in Section 5.3.1.1 shed light on the limited impact the terminal infrastructure had on truck turnaround times. Sections 5.3.1.3 and 5.3.1.4 highlighted that frequent and clustered truck arrivals were likely significant congestion factors. The simulation modelling scenario analysis provided additional support towards the impact of coordination on congestion (Section 5.3.2). The researcher's preliminary results following each research stage also shaped this finding, mainly: that terminal infrastructure was a symptom rather than a cause of congestion (ER-3, p. 130), that supply chain behaviours, partially emerging from that misaligned incentives (ER-5, p.131, WR-2, p.165), such as restarting operations following disruptions facilitated (ER-4 , p. 131), and inflexibility (WR-3 p.165) facilitated the appearance of congestion.

6.2.2 Congestion, particularly with increased recurrence, can have implications on supply chain competitiveness and resilience (KF-2.)

The interpretation of the analyses and results that led to this key finding can be identified as follows: Stage 1: Exploration and Stage 2: Design Workshops grounded theory-based coding presented in Sections 5.2.1.2 and 5.3.3.2. The exploratory data analysis on truck turnaround times (Section 5.3.1.2) also revealed the large variation in turnaround times. The analysis results supported the researcher's preliminary insight with regards to the implications of congestion on the supply chain (see ER-7 p.132).

6.2.3 Interpretation: A Model of Congestion Factors

Congestion is an emergent supply chain property. Across the three cases, the appearance of congestion was facilitated by a series of factors and their interrelationships, most of which pertained to the different entities operating in the supply chain. Congestion was, therefore, across the three cases, an issue mainly related to the interaction of behavioural, social and technical factors within organisations, supply chains and between supply chain segments converging at the same facility. Figure 54 presents the model of factors interacting at the different levels of analysis which emerged from aggregating the congestion factors findings in this applied research.

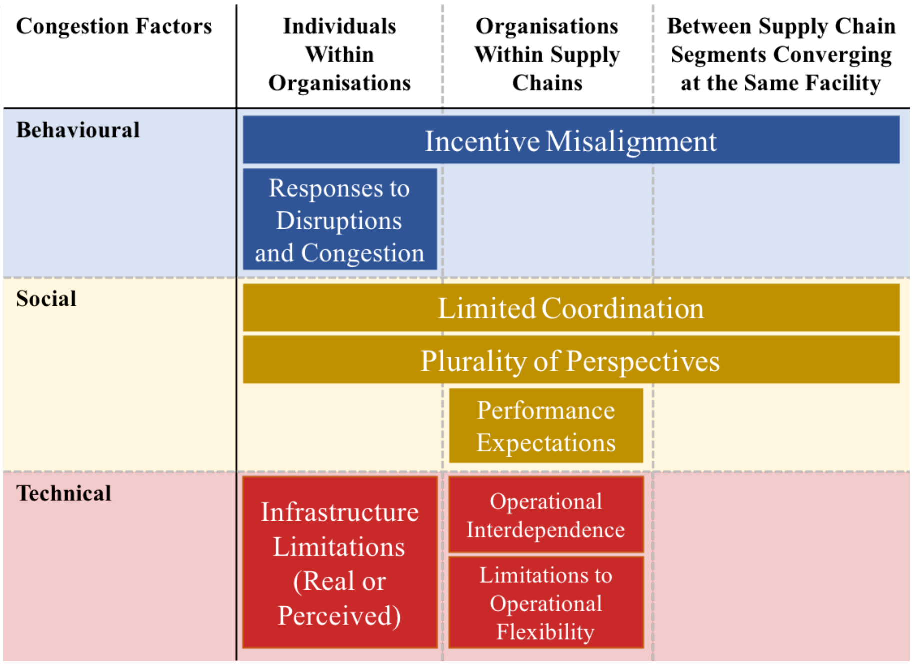

Figure 54 Congestion Factors Model

The model in Figure 54 categorises factors into behavioural, social and technical. Behavioural factors relate to the actions of individuals or entities. Social factors pertain to the interactions between individuals and entities. Technical factors pertain to assets (infrastructure, equipment and technology artefacts) and the interactions of individuals or entities with these assets. This distinction is essential because in all case studies, the terminal, where congestion was most visible, was considered the primary cause of congestion. However, where data were available to investigate the adequacy of terminal infrastructure, there was limited evidence supporting the claim that congestion was caused by inadequate infrastructure. Rather, it was evident that the way in which assets were used was part of the problem. Rather, it was evident that how assets were used was part of the problem. The lines between the three factors are purposely dotted to illustrate a level of interaction between the factors themselves. Several interactions have been identified through the data analysis (see Figure 33, p.112). However, the researcher acknowledges that this list of interactions identified in this research may not necessarily be exhaustive.

Congestion factors also interact across different levels of analysis, from individuals within organisations, organisations within supply chains and organisations between supply chains converging at the same facility. The organisations between supply chains converging at the same facility level is worthwhile discussing in further detail. Individuals in organisations and organisations within supply chains are generally directly or indirectly bound to one-another through contracts. In this research, information and communication lows between companies tended to follow companies' contractual links. However, just because material flows of organisations intersect does not necessarily imply that the same organisations share information on these flows. For example, it is uncommon that haulage or transport contractors have a contract amongst themselves. Congestion often occurred in the void created by the lack of information and communication flows between the different organisations converging at the same facility.

The congestion factors uncovered in this research are presented in the order of priority as interpreted by the researcher. These are limited coordination, incentive misalignment, operational interdependence, the plurality of perspectives, limitations to operational flexibility, responses to disruptions and congestion and infrastructure limitations.

The limited coordination was, in this research, one of the key factors leading to congestion. The impact of improved supply chain coordination on congestion was evidenced both analytically in the simulation model as well as empirically, in the experiment conducted by the participants in Case A. Neither the simulation model nor the experiment were repeated in the other two cases. However, the researcher considers that there are sufficient similarities in the structure of the supply chains and types of issues faced across the three cases that improving coordination in Cases B and C would yield similar impacts as they did in Case A. It was interesting to observe that, although congestion and the limited coordination were often long-standing issues, attempts to address these issues in an integrated manner were rare.

Incentives within organisations, supply chains and between supply chain segments were often misaligned. The misalignment of incentives was partially related to fragmentation – both between and within organisations. Organisational incentives, mainly financial, were often conflicting, particularly for organisations offering similar types of services. Consequently, there was a high likelihood that short-term organisational goals, such as fulfilling orders or improving profitability, would take precedence over collaborative approaches to address supply chain issues.

In all three cases, there were relatively few direct incentives for the terminal operators to mitigate congestion. The terminal operator generally did not have a contractual relation with the transporters themselves. Often, the transporters were subcontracted by chipping or harvesting companies who were themselves contracted by forestry companies. It was therefore rare that the terminal operator would experience significant consequences of congestion apart from the frustration of the truck operators, transporters and contractors. As long as the terminal operator would continue to reach volume or revenue targets, congestion did not seem to be perceived as a significant issue. In Case C, the forestry company owning the terminal operator, mentioned in their contracts with chipping and haulage contractors an expected 45-minute average truck turnaround time at the terminal facility. However, it appeared that explicitly mentioning the average truck turnaround time may have created unrealistic expectations which in fact may have contributed to some of the terminal users' frustrations. Given that in the other two cases, the average truck turnaround times seemed often misinterpreted with a maximum threshold, it is likely that an approach where the average truck turnaround time is agreed upon contractually will lead to unintended consequences. However, several consequences of congestion may provide an incentive for the terminal operators and other supply chains stakeholders to participate in mitigating congestion

It was interesting to observe that a large proportion of congestion mitigation efforts were undertaken in Case A and were supported by the terminal operator. A significant difference between the supply chain setup of Case A and the other two cases is that the terminal operator in Case A was a government business enterprise (GBE) acting as a storage and wharfage service provider. In Cases B and C, the terminal operator was a privately-owned entity, associated with or owned by a forestry company. In Case A, participants often discussed the terminal operator's responsibility for the broader community and industry. It was likely that the terminal operator's perceived responsibility for the broader community was associated with the public ownership structure of the terminal operator. It was possible that the responsibility for the broader community may have catalysed the involvement of the terminal operator in congestion mitigation.

The technical interdependence of operations within supply chains was also an important congestion factor. The interdependence of operations refers to technical aspects in supply chains for which tasks must be completed in a set sequence. A high level of interdependence occurs in synchronous operations (e.g. in Case C, wood chipping cannot occur separately from truck loading), whereas lower levels of interdependence occur when operations can be completed asynchronously. A high level of interdependence of operations was particularly problematic in Cases B and C. Several participants recognised that congestion was a manifestation of highly inter-related production processes that affected the logistics chain. Conversely, in Case A, production operations were largely separated from the logistics task, which led to fewer operational interdependence challenges.

The plurality of perspectives amongst stakeholders was also a congestion factor. From the individual participants' perspective, congestion was generally considered a nuisance outside the control of the participant or organisation. This perspective meant that congestion was an issue for which someone could be blamed for. Generally, the terminal as the place of manifestation of congestion, or the terminal operator as the controlling entity, were the supply chain elements seen as responsible for congestion. Furthermore, individual participants, particularly transport and chipping companies, also rarely recognised their role in the generation of congestion. Perspectives varied between stakeholders within supply chains and supply chain segments. This was most evident in Case A where there was limited agreement on which piece of terminal infrastructure or equipment was causing congestion. In the absence of agreement and a common perspective amongst stakeholders, individuals' and organisations' behaviours in the appearance of congestion would not be evident to the stakeholders themselves, meaning that such behaviours would continue to exist.

The technical limitations to operational flexibility within supply chains played a role in congestion development. These limitations were particularly evident for logistics flows. The impact of stakeholders' inability to redirect cargo to different facilities during periods of high congestion or operational disruptions was highlighted on several occasions in Cases B and C. In many situations, the stakeholders were aware that their behaviours contributed to congestion aggravation. However, since no alternative way was perceived, congestion became the reality of doing business.

The way individuals responded to congestion and to operational disruptions was a contributing factor to congestion. Following operational disruptions caused by weather, poor quality cargo or breakdowns, loaded trucks waiting at their depots would often swarm the re-opened facility. This behaviour would generally lead to high waiting times. In Case B, the facility began operations at 6 am. However, trucks would sometimes be waiting from 3 am on the terminal premise in the hope of avoiding congestion. The situation in which trucks would queue prior to the facility’s opening time inadvertently created morning congestion that would take hours to clear. While detrimental for the overall congestion situation, this response appeared rational from an individual perspective as it ostensibly allowed truck operators and organisations to ensure a first daily delivery.

Finally, infrastructure limitations played a role in the appearance of congestion. Clearly, congestion will likely ensue if the upper physical capacity limit of a piece of infrastructure or equipment is reached. Therefore, mitigation will require an extension or expansion of the available infrastructure or equipment base. However, in all cases in this research, terminal infrastructure's capacity limitation was only an issue for short periods of time. In most cases, the terminal would manage to process the desired daily, weekly, monthly or yearly throughput. Infrastructure limitations primarily related to the way in which the infrastructure was used rather than physical capacity. Furthermore, infrastructure limitations were, in some cases, only perceived and not necessarily grounded in evidence. However, where data were not available, it was challenging to verify or contradict participants’ claims and beliefs.

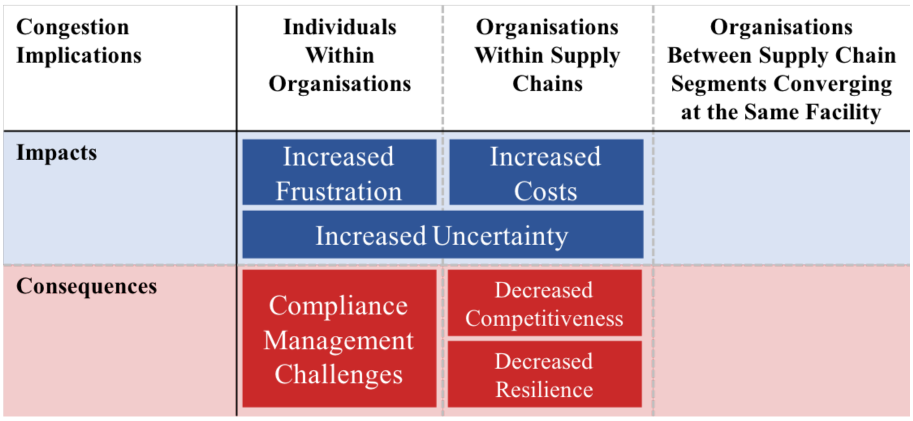

Figure 55 Congestion Implications Model

The appearance of congestion also brought forth several implications for individuals and organisations within supply chains. Figure 55 presents the congestion implications identified in this research. Implications are categorised into impacts, short-term, direct and visible aspects, and consequences, medium- to long-term, less visible and indirect aspects of congestion. The lines between the implications are purposely dotted to illustrate a level of interaction between the aspects themselves. Several interactions have been identified through the data analysis (see Section 5.2.1.2 p.119). However, the researcher acknowledges that the list of interactions identified in this research may not necessarily be exhaustive.

The congestion impacts identified were increased uncertainty, costs and frustration. The congestion consequences were: decreased competitiveness, decreased resilience and compliance management challenges. These implications are presented in the order of priority as interpreted by the researcher.

Increased uncertainty for logistics operations appeared to be one of the critical areas where congestion had an impact. Increased uncertainty was strongly related to the increase in frustration, as individuals and organisations were unaware and unable to maintain control over their schedules. Furthermore, increased uncertainty also led to increased costs. These impacts had a strong influence on the congestion consequences.

The competitiveness of the supply chain suffered due to congestion. As costs increase for individual organisations, the costs in the entire supply chain also rose. These costs may not necessarily rise immediately, due to existing contractual arrangements. The rising supply chain costs would need to be incorporated in the commodity cost, therefore reducing the chain's profitability. Less profitable, more costly supply chains have less chances of competing globally, particularly for commodity products.

The resilience of supply chains was also impacted by congestion. One participant described congestion as "*death by 1,000 cuts*". The participant in that context was referring primarily to port access costs. However, the metaphor is useful for describing multiple facets of congestion which are not necessarily evident at first sight. In this research, congestion, particularly with increased recurrence, was found to affect truck operators' compliance and fatigue risks, the bankruptcy risk of chipping and haulage contractors, or the risk of non-fulfillment of contractual requirements. Although mostly manifesting themselves at an individual organisation level, such consequences of congestion can affect the resilience of the entire supply chain. If chipping and transport contractors go bankrupt, the forestry companies' ability to deliver is impaired as is the terminal's financial viability. Similarly, if contractual requirements with pulp and paper companies are not fulfilled, the competitiveness of the chain can be impaired which can in turn affect all companies in the supply chain.

Another consequence of congestion was the increase in compliance management challenges. One of the key aspects of compliance management in the Australian context was the driver *Fatigue Management* regulation. A large part of fatigue management was managing drivers' working hours and breaks. The increased uncertainty associated with congestion meant that managing schedules and rosters became increasingly difficult. Therefore, truck operators would be more likely to drive over time, risking fines and facing heightening accident risks.

The next sub-section presents a discussion of the findings in light of the extant research literature, highlighting this research's contributions.

6.2.4 Discussion

This research has found that congestion is a supply chain property emerging from the interaction between social, technical and behavioural factors. The supply chain stakeholders do not necessarily share a common perspective and understanding of congestion. The implications of congestion affect individual organisations and the supply chain as a whole.

The research literature in the logistics space tends to be segmented into discrete research foci. These foci can centre either on different organisation types (e.g. terminal operators) or transport modes (e.g. land- or sea-based). The problems defined within these research foci are often addressed with an efficiency or cost focus (Andersson *et al.*, 2010; Ambrosino and Caballini, 2015; Gansterer and Hartl, 2018). Therefore, the factors causing port congestion relate to the terminals themselves and can include infrastructure or transport capacity limitations, labour and equipment shortages, weather and resource limitations (Meersman, Voorde and Vanelslander, 2012). In the context of landside congestion management at marine terminals, there is limited understanding of the factors conducive to the appearance of congestion, particularly those that may emerge outside the terminals. This research contributed to the research literature by highlighting that a more holistic approach, integrating the sea-, terminal and landside elements of the chain can reveal additional aspects relevant to congestion. This research has identified a series of social, technical and behavioural factors that are conducive to the appearance of congestion: limited coordination of logistics activities, interdependence with other supply chain operations, misaligned incentives, inadequate terminal infrastructure, operational disruptions and lack of supply chain flexibility. Importantly, this research has also highlighted that across the range of supply chain stakeholders, perceptions on congestion and contributing factors vary significantly. Some of these factors have been identified by researchers, such as conflicting goals, causal operational relations in coordination challenges (Gumuskaya *et al.*, 2020). Therefore, this research questions the assumption landside congestion in marine terminals is a terminal problem that falls under the responsibility of terminal operators.

The congestion factors described in the literature (see Table 5, p. 38) are compared with those identified in this research. Although recognised as a congestion factor in the extant literature, the inadequate terminal infrastructure was only a perceived congestion factor in this research. Indeed, the inadequate terminal infrastructure was rather a symptom of other congestion factors rather than a factor in itself. Operational disruptions such as weather or accidents also played a role in generating congestion. However, in this research, individuals and organisations' behavioural responses to operational disruptions seemed to play a more important role than the disruptions themselves. In this research, regulations and policies played a limited role in generating congestion. Imperfect information flows are also considered in the extant literature as a congestion factor. This research identified limited coordination as one of the most important congestion factors. Coordination is a mechanism based on sharing and acting on information between the different parties. In this sense, this research's findings point towards the fact that imperfect information flows contribute to the appearance of congestion. However, the researcher posits that improved information flows would likely be insufficient to address congestion. The adequate actions on the information flows would have to be defined to address congestion.

The congestion mitigation approaches considered in the literature can be classified in three broad categories: additional terminal infrastructure (Giuliano and O'Brien, 2007), information technology for automating processes (Heilig and Voß, 2017) or coordinating truck arrivals (Huynh, Smith and Harder, 2016), and policies and pricing mechanisms (Giuliano and O'Brien, 2007; Holguín-Veras *et al.*, 2011; Bentolila *et al.*, 2016). Generally, the impact of individual approaches to mitigating congestion are evaluated, with a strong preference towards terminal appointment systems (Chen, Govindan and Yang, 2013; Minh and Huynh, 2017; Li *et al.*, 2018; Zhang, Zeng and Yang, 2018). This research has contributed to the research literature by comparing the effectiveness of several congestion mitigation approaches using simulation modelling. This comparison highlighted that additional infrastructure was often less effective than improved coordination using appointment systems. Appointment systems were found in this research to be one of the most effective approaches to mitigating congestion. This finding is aligned with other researchers' preference for appointment systems (Huynh, Smith and Harder, 2016; Schulte *et al.*, 2017; Caballini, Gracia and Sacone, 2018). However, this research has also provided evidence that the appointment system's effectiveness is related to the congestion factor it helps mitigate. Thus, in this research, a primary congestion factor was the limited coordination which can be effectively addressed using an appointment system. The simulation model has also provided evidence that automation technology can improve operational efficiency and reduce truck turnaround times but may have limited impact on waiting times and therefore congestion. This further supports the argument that a congestion mitigation approach's effectiveness is related to the congestion factor addressed. In this research, infrastructure efficiency was not a significant factor contributing to congestion. Therefore, improving the efficiency of terminal infrastructure had limited impact on congestion. Importantly, this research found that the supply chain coordination mechanisms, instantiated by the participants and supported by information sharing, positively impacted the truck turnaround times and congestion.

Research on landside congestion management in bulk cargo marine terminals is limited. To date, no research has investigated landside congestion management in bulk marine terminals for forest products. An overwhelming proportion of research in landside congestion management has been focused on container terminals (Davies and Kieran, 2015; Chen and Jiang, 2016; Torkjazi, Huynh and Shiri, 2018). However, containerised and bulk transportation share similarities (Bugaric, Petrovic and Jeli, 2015). This research has contributed to the research literature on landside congestion management by investigating this issue in bulk cargo marine terminals. Furthermore, in this research, several congestion mitigation mechanisms, such as automation technology or appointment systems, were adapted from the container terminal literature and used in the context of bulk cargo marine terminals. Therefore, the researcher highlights the possibility that other insights obtained in the context of container terminals may be valid for bulk cargo marine terminals and vice-versa.

The implications of congestion typically relate to increased logistics costs (Loh and Thai, 2015; Huynh, Smith and Harder, 2016), increased frustration, risk of accidents and a decrease in overall transport performance (Meersman, Voorde and Vanelslander, 2012). This research provided evidence to support the argument that increased costs, frustration and accident or compliance breaches risks are some of the most visible implications of congestion. This research has also highlighted that, at a supply chain level, congestion can affect the competitiveness of the supply chains against other, similar chains. Therefore, the researcher highlights the possibility that other insights obtained in the context of container terminals may be valid for bulk cargo marine terminals and vice-versa. Resilience in supply chains appears significantly intertwined with high-impact low-probability unexpected disruptions (Bhamra, Dani and Burnard, 2011). However, other authors contend that ongoing system strain from the accumulation of small scale events can have similar consequences as a large scale event (Rudolph and Repenning, 2002; Vogus and Sutcliffe, 2007). This research supports the argument that congestion can be viewed as an ongoing system strain that can significantly impact resilience and supply chain competitiveness.

The next section discusses the key findings most related to the second research question.

6.3 Generating a Holistic Understanding of Landside Congestion and Mitigation Mechanisms (RQ-2)

This section provides an interpretation and discussion of the key findings (***KF-3***. and ***KF-4.***) that relate primarily to the second research question: *How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?* These findings have been ordered in terms of priority as interpreted by the researcher.

6.3.1 The participatory design approach utilised in this research was effective in enhancing understanding and the emergence of congestion mitigation mechanisms (KF-3.)

The interpretation of the analyses and results that led to this key finding can be identified as follows: Stage 3: Evaluation (Section 5.4.1) where the understanding of participants and the congestion mitigation approaches designed were highlighted. The evaluation of the impact of the mitigation approaches implemented (Section 5.4.2) also revealed that the measures were effective in mitigating some of the congestion. The researcher's understanding of congestion factors and mitigation approaches was also greatly improved and is highlighted in the range of congestion factors identified (Sections 5.2.1.1.1 to 5.2.1.1.7) and the congestion mitigation approaches investigated using simulation modelling (Section 5.3.2). The performance expectations of participants with regards to truck turnaround times emerged in both research stages (Sections 5.2.1.1.7 and 5.3.3.1.5). These findings supported the preliminary results with regards to lack of a common definition of congestion amongst participants and the potential unintended consequences of setting average truck turnaround times in contractual agreements (see ER-1, p.130 and WR-4, p.165) and the conceptualisation of congestion as an emergent property of the supply chain (WR-1, p.164).

6.3.2 Conventional measures of congestion, used in isolation from other indicators, tend to misrepresent congestion (KF-4.)

The interpretation of the analyses and results that led to this key finding can be identified as follows: Stage 2: Design Workshops, quantitative exploratory data analysis results (Section 5.3.1.2, 5.3.1.3, 5.3.1.4), simulation modelling results (Sections 5.3.2) and performance expectations of participants with regards to the average truck turnaround times (Sections 5.2.1.1.7 and 5.3.3.1.5). The perceptions of the participants captured in the qualitative data analysis were compared with the quantitative data analysis to reveal that there were some discrepancies and potential misinterpretation of the concept of average (ER-1, p.130 and WR-4, p.165).

6.3.3 Interpretation: A Participatory Mitigation of Congestion Framework

In synthesizing the insights developed in this research, a framework for participatory mitigation of landside congestion emerged (see Figure 56). This framework can be used as a sensitising device for researchers investigating congestion mitigation in bulk cargo marine terminals. This framework also highlights the links between the congestion factors and the mitigation mechanisms and presents an approach for developing of contextually-adapted mitigation mechanisms. The four stages presented in this framework include: 1) Explore congestion perspectives; 2) Align perspectives and develop a common vocabulary; 3) Co-design and agree on response and actions for congestion mitigation; 4) Evaluate impacts and benefits. Insights obtained in each stage inform the next stages. Several iterations of the same stage may be required, depending on the participants.

In the first stage, the participants' perceptions of congestion are explored. This stage entails collecting and analysing qualitative data through interviews and site visits. The emerging perspectives on congestion factors can be synthesised with the model presented in Figure 54 (p.181). Similarly, the perspectives on congestion consequences can be summarized with the model of congestion implications Figure 55 (p. 184). The perspectives captured in this stage will inform the subsequent stages.

In the second stage, the variety of perspectives across participants is discussed to develop a common vocabulary regarding congestion. In this stage, quantitative data can be analysed, focusing on aspects and perspectives uncovered in the first stage. In this research, the exploratory data analysis in Case A focused first on understanding the impact of terminal equipment on congestion, given the participants' accounts on their role in congestion. The quantitative data analysis can corroborate or question existing beliefs and perspectives. Furthermore, the potential impact of congestion mitigation approaches from research or practitioner literature as well as approaches suggested by the participants should be modelled. The modelling results can help facilitate the alignment of perspectives across stakeholders on the potential congestion mitigation responses.

The co-design of congestion responses and actions entails defining the approach to be taken and individual stakeholders' roles. It is important that the congestion factors and implications previously identified are considered in this process to ensure the alignment between cause and response. Furthermore, the congestion factors model may also highlight barriers to implementing a particular response. The digital tools that can enable or facilitate a congestion mitigation response can be identified. Technology comes after the factors are identified, rather than before. The main reason for this approach is to avoid the perception that digital tools will solve a problem without understanding the role of technology. Both the perception alignment and co-design stages can be done during design workshops. Finally, the impact and benefits of the responses designed and implemented should be evaluated. Evaluation should include the impact on participants' perceptions and on performance metrics. Where possible, before-and-after comparisons should be drawn up. The learnings and vocabulary can therefore inform the subsequent iterations of the framework.

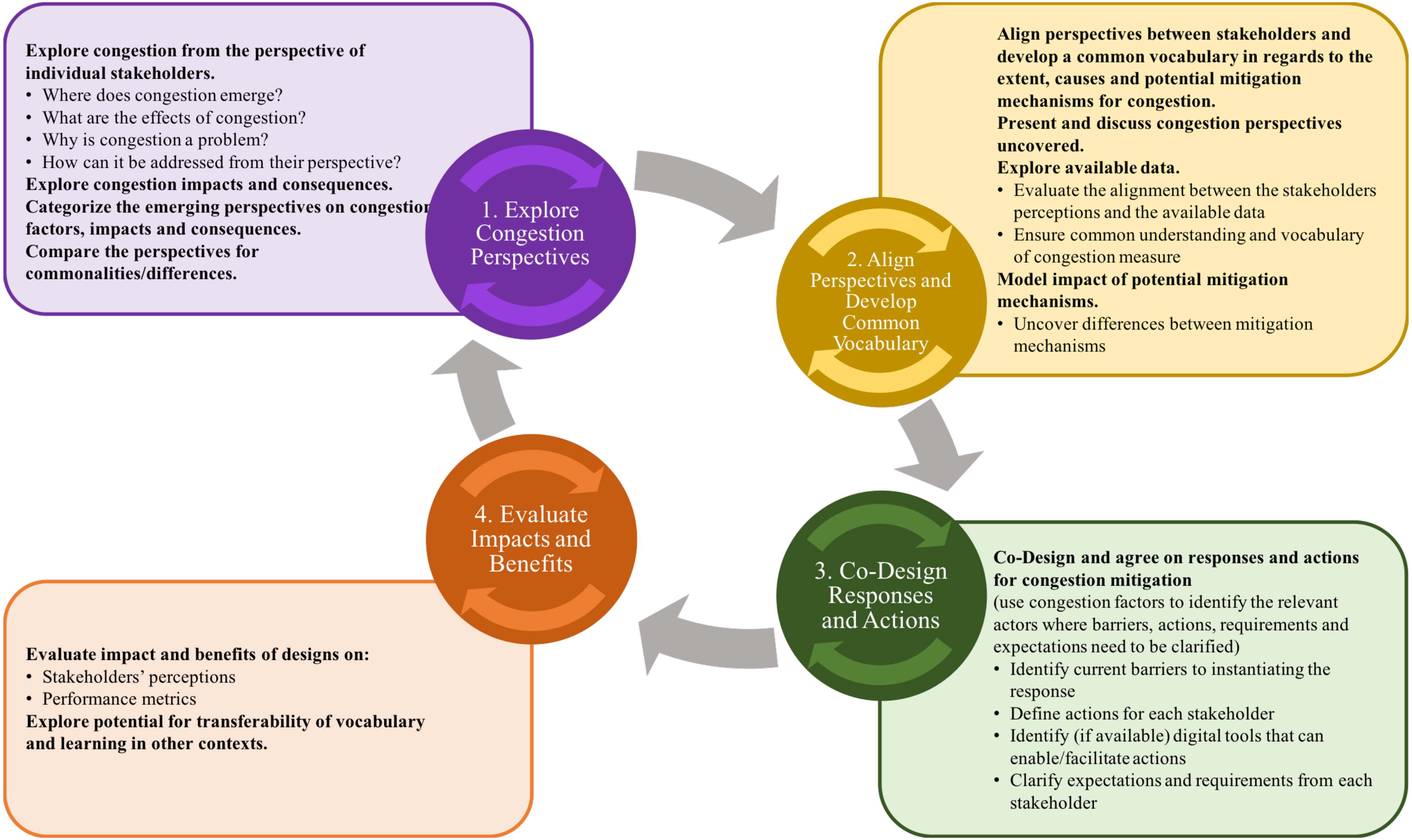

Figure 56 A Framework for Participatory Mitigation of Landside Congestion

Several aspects were critical for generating the insights and impacts of the participatory design approach employed in this research:

- The collection, analysis and comparison of quantitative and qualitative data.
- The involvement of supply chain stakeholders in the exploration of congestion and in the design of mitigation mechanisms.
- The types of measurements used for evaluating the intensity of congestion.

The use of quantitative and qualitative data was critical in this research. Qualitative data helped improve the researcher's understanding of participants' perceptions, motives and feelings regarding congestion. Quantitative data allowed the researcher to understand better whether the participants' perceptions were based on patterns or individual, potentially over-represented, events. In several instances, these comparisons led to some of the most significant preliminary findings of this research: that the terminal infrastructure in Case A was not a significant congestion factor despite the participants' perceptions and that the participants' interpretations of average truck turnaround time values were somewhat disconnected from the measure's meaning.

The involvement of supply chain stakeholders in congestion exploration and mitigation mechanisms design highlighted the problem's complex nature. A large proportion of the congestion factors identified related to the supply chain. The participant's understanding of their role in congestion and potential role in its mitigation was useful in catalysing mitigation efforts. It is interesting to observe that, although the participants in all cases expressed interest in continuing the workshops, the participants in Case A were the only ones that agreed-upon designs to mitigate congestion and also implemented such designs. Several factors likely contributed to the differences in progress across the three cases:

- In Case A, the willingness to share information with other participants and with the researcher seemed slightly higher than in other cases. Although all terminal operators shared weigh-bridge data with the researcher, the chipping and transport operators were reluctant to provide the researcher with access to any data. The researcher could construct the terminal simulation model in Case A with assistance from the terminal operator, the forestry companies and one of the transporters who provided the various data inputs required. It is possible that this additional willingness to share or collaborate may have translated in.
- The simulation model developed in Case A may have also contributed to the participants' willingness to fully engage in the design process and implement the congestion mitigation mechanisms designed. The researcher suspects that the simulation model provided the participants with evidence of potential impact which may have acted as a flagpole to direct participants' attention and efforts.
- The duration of the researcher's exposure and interaction with the participants in each case study differed, primarily due to travel time and costs constraints. It is possible that the additional time spent by the researcher with the participants in Case A facilitated the development of trust and contributed to the participants' willingness to engage during the workshops fully.

- As highlighted in the previous section, the fact that the terminal operator in Case A was publicly owned may have catalysed efforts as congestion was seen as an issue that affected the broader community and the industry as a whole.
- The distribution of power between the terminal operators, forestry companies and transporters appeared slightly more balanced in Case A than in other cases. In Case A, the forestry companies were the terminal operator's customers, which was providing wharfage and storage services. In Cases B and C, the chipping and haulage operators were contractors or suppliers for the terminal operator (or owning entity).

The participatory design approach also highlighted several potential issues in the way participants used, understood and interpretation of average values. The exploratory data analysis revealed that a large proportion of truck turnaround times were smaller than the average acceptable threshold. However, the variability of truck turnaround times was generally large, and usually biased towards high values. Interview analysis revealed that it was often the uncertainty and variability of truck turnaround times which caused the most significant issues. The average figures could, in fact, obscure these occurrences of high turnaround times. Consequently, congestion mitigation strategies aimed at reducing the average truck turnaround time, whilst successful in doing so, may fail to address the actual issue. The simulation modelling results revealed that in the weigh-bridge automation scenario, the truck turnaround time average decreased by approximately 20%, however the truck waiting times did not change significantly. In other words, improvements in terminal operational efficiency while reducing average turnaround times may fail to address landside congestion. Thus, it is important to look past the average to understand the distribution of truck turnaround times and the effect congestion mitigation approaches have on this distribution.

In this research, the focus on the distribution shape was achieved through visualisation techniques, primarily density plots and histograms as well as adapted performance metrics. Visualisation techniques were applied to each case study's data and the simulation model scenarios. Analysis of the appointment system scenario illustrated a reduction in the truck turnaround time distribution variability and a reduction in its skewness. The terminal appointment system scenario was considered an illustration of coordination mechanisms that can be instantiated to mitigate congestion. This understanding guided the participants' attention towards information system and their potential contribution to the coordination mechanisms. Several mechanisms that helped ameliorate landside congestion emerged and were implemented as a result of Stage 2: Design Workshops.

The next sub-section presents a discussion of the findings in light of the extant research literature, highlighting this research's contributions.

6.3.4 Discussion

From a methodological perspective, this research has provided evidence supporting the use of an adapted participatory design approach to better understand congestion and the emergence of situated congestion mitigation designs.

The research literature in the logistics space tends to be segmented into discrete research foci. These foci can centre either on different organisation types (e.g. terminal operators - Zhao and

Goodchild, 2010, 2013) or transport modes (e.g. land- Gansterer and Hartl, 2018; Van der Horst and De Langen, 2018 or sea- Christiansen *et al.*, 2013; Halvorsen-Weare, Fagerholt and Rönnqvist, 2013). Consequently, landside congestion is typically understood as a problem which fits in one of these segments, the marine terminal. This is primarily because one of the most visible consequences of congestion, queues, emerges in marine terminals.

Landside congestion management is typically addressed using quantitative approaches, through simulation (Huynh, Walton and Davis, 2004; Sharif, Huynh and Vidal, 2011; Huynh, Smith and Harder, 2016; Li *et al.*, 2018), queuing (Guan and Liu, 2009; Chen, Govindan and Golias, 2013; Zhang, Zeng and Yang, 2018) or optimisation models (Zehendner and Feillet, 2014; Ambrosino and Caballini, 2015; Chen and Jiang, 2016; Torkjazi, Huynh and Shiri, 2018). Generally, these approaches aim to improve the efficiency of terminal operations (Zhao and Goodchild, 2010, 2013) or, in some cases, to reduce truck turnaround times at the terminal (Huynh, 2009; Chen, Govindan and Yang, 2013; Ambrosino and Caballini, 2015). Although useful, such quantitative approaches do not lend themselves well to the exploration of aspects of the problem that cannot be easily quantified.

The empirical nature of this research was a critical aspect of our work. The findings in terms of congestion factors from Stage 1: Exploration were empirically validated or refined with the participants in the subsequent research stages. Two of the most influential and highly cited papers in the domain of landside congestion management are empirical investigations (Giuliano & O’Brien, 2007; Morais & Lord, 2006). The issues highlighted by these papers regarding the ineffectiveness of appointment systems and other congestion mitigation methods in practice have been the primary driver for this work. Even though these papers are more than a decade old, the extant research literature has, to date, failed to answer to the question of how theoretical benefits derived from congestion mitigation be achieved practice.

Huynh *et al.* (2016) highlight that research on truck appointment systems has yet to take into account the complexity of the hinterland logistics system and Torkjazi *et al.* (2018) present an optimisation model which highlights the benefits of balancing the interests of terminal operators and transporters in managing the parameters of appointment systems. This research built on this knowledge by considering a diverse range of stakeholders and perspectives (terminal operator, transporters and port users) to unpack that complexity and present an approach through which congestion mitigation mechanisms can be developed and aligned with congestion factors. The framework for participatory mitigation of landside congestion developed in this research represents this work's contribution to this body of knowledge. The framework provides a practical approach to understanding the factors leading to congestion and also provides a way for participants to develop contextually relevant congestion mitigation mechanisms.

The findings of this research revealed that the supply chain participants had a diverse set of perspectives on congestion, its causes and implications. The comparison between the qualitative and quantitative data also revealed that the participants' latent expectations regarding congestion also influenced their perception of the phenomena. This lack of a common understanding of the problem has been acknowledged in the research literature aimed at addressing ‘wicked’ problems (Mingers and Rosenhead, 2001; Smith and Shaw, 2019).

The participatory design approach employed facilitated the development of a common understanding between participants, a common vocabulary and mutually acceptable approaches to mitigating congestion. Although participatory design has been predominantly applied in the development and implementation of information systems in the healthcare sector (Pilemalm and Timpka, 2008; Pihkala and Karasti, 2016; Østergaard, Simonsen and Karasti, 2018; Tang *et al.*, 2018) or enterprise resource planning systems implementation (Pries-Heje and Dittrich, 2009), it had not applied in a logistics context. This research's outcomes provide evidence that this approach can be successfully used in a logistics context to tackle complex challenges. Notably, the participatory design approach is useful in exploring an issue and supporting the development and implementation of mechanisms aimed at addressing an issue.

A large portion of the research on landside congestion management focuses on appointment systems (Schulte *et al.*, 2017; Riaventin and Kim, 2018; Torkjazi, Huynh and Shiri, 2018). This is most likely because appointment systems are an interesting problem to optimise. So, in most cases, first the technology is chosen and then the operating parameters are tweaked. This work's empirical nature meant that participants' learning process affected how the participants themselves were managing their operations. In effect, the participants tweaked the operating parameters of their work. Thus, when the decision to explore the implementation of an appointment system, the supply chain was mature enough to see this technology as a logical progression of their congestion mitigation efforts.

The participatory design approach helped the researcher define congestion as a supply chain phenomenon. The research literature on landside congestion management in general tends to assume the term congestion is well-understood rather than to define it explicitly. This generated some challenges when understanding the impact of different factors reported as contributing to congestion as well in evaluating the effectiveness of reported congestion mitigation responses. In the broader domains of transportation and road traffic congestion has been defined as *"the presence of delays along a physical pathway caused by the presence of other users"* (Kockelman, 2004). Unfortunately, this rather general operational definition has proven to be of limited use in understanding the phenomenon. The analysis revealed that participants had a preconception of a level of acceptable congestion, however very few participants expressed the level and rationale behind this acceptable level. The participants that explained the rationale behind the acceptable level of congestion mentioned that transporters' calculations were based on an average truck turnaround time at the terminal. These calculations were generally factored into tender documents to estimate operational costs. However, these calculations created an expectation of acceptable congestion and therefore appeared to guide the participants' perceptions on the levels of congestion. Based on the coding process drawing on the principles of grounded theory of the qualitative data emerging in Stage 1: Exploration, this congestion is defined in this research as "*An emergent symptom of logistics systems, characterised by higher-than-expected delays, generally manifesting at marine terminals, caused by a plurality of factors and their interactions and a multitude of stakeholders' perspectives and associated individual response behaviours*". The analysis highlighted the importance of interplay between social, behavioural and technical aspects in the supply chain and detracted from the more traditional techno-centric perspective of addressing congestion.

The discrete-event simulation model of the marine terminal proved to be a useful tool in generating understanding amongst participants and supporting the development of mitigation approaches. The findings generated in this research support the research literature on simulation modelling with respect to the usefulness of simulation to explore the effect of a limited number of variables (Manuj, Mentzer and Bowers, 2009) and the development of "What-if" scenarios (Crainic, Perboli and Rosano, 2018). Importantly, the simulation approach also supported the development of tangible solutions for using insights gained from modelling (Dragović, Tzannatos and Park, 2017). The simulation model's construction was heavily based on qualitative interview and observation data. Similarly, the scenario analysis results underwent a process of questioning and interpretation during the workshops before findings were integrated in decision making.

The simulation model was developed using truck arrival and geo-positioning data. Whilst most models use truck arrival data collected through manual measurements (Guan and Liu, 2009; Zhang, Zeng and Yang, 2018), in a large proportion of cases, service times of different terminal assets have to be assumed to follow a particular distribution. These assumptions may reduce the accuracy of the models developed. In this research, truck geo-positioning data over 3.5 months were used the estimate infrastructure service times and provided a relatively robust and accurate model of terminal operations.

The next section discusses the key findings answering the third research question.

6.4 The Role of Information Systems in Understanding and Mitigating Landside Congestion (RQ-3)

This section provides an interpretation and discussion of the key findings (***KF-5.*** and ***KF-6.***) that relate primarily to the third research question: *What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?* These findings have been ordered in terms of priority as interpreted by the researcher.

6.4.1 Information systems can contribute to better understanding and mitigation of congestion (KF-5.)

The interpretation of the analyses and results that led to this key finding can be identified as follows: Stage 2: Design Workshops simulation modelling results (Section 5.3.2), highlighting the potential impact of a terminal appointment system and weigh-bridge automation technology. Information sharing practices were discussed (Section 5.2.1.3.3) and the challenges concerning information asymmetry (Section 5.2.1.3.4) and the behavioural expectations following information sharing (Section 5.2.1.3.5). The coding process drawing on the principles of grounded theory in Stage 2: Design Workshops strengthened the exploration findings concerning information sharing (Section 5.3.3.3.1), information asymmetry (Section 5.3.3.3.2) and behavioural expectations (Section 5.3.3.3.3). These results were further refined in the preliminary results on the initiation and continuation of information sharing (WR-7, p.167 and WR-8, p.167). The preliminary results were supported by evidence of implementation and adoption of information sharing mechanisms by participants (Section

5.4.1) following a reduction of information asymmetry and establishment of behavioural expectations.

The evaluation semi-structured interviews (Section 5.4.1) revealed that, anecdotally, the information sharing mechanisms implemented by the participants had had an impact on sea- and landside logistics clashes. The analysis of the weigh-bridge data captured during the coordination experiment in Case A (Section 5.4.2) provided evidence of the experimental approach's effectiveness in reducing congestion.

6.4.2 The participants' perceptions of the expected benefits of digital tools to mitigate congestion were often not grounded in evidence (KF-6.)

The interpretation of the analyses and results that led to this key finding can be identified as follows: Stage 1: Exploration grounded theory-based coding where the use of existing digital tools primarily for monitoring and compliance (Section 5.2.1.3.1) and partially to support decision making (Section 5.2.1.3.6) as well as the expectation that novel information tools to enhance visibility (Section 5.2.1.3.7) and organisational performance (Section 5.2.1.3.8) were discussed. The performance improvement expectations of novel digital tools (Section 5.3.3.3.4) were also discussed in the context of enabling visibility (Section 5.3.3.3.5) during the workshops. The comparison between the current use of digital tools and their expected impact was captured in the preliminary results of Stage 1: Exploration and Stage 2: Design Workshop (ER-8, p.132 and WR-6, p.166).

The next sub-section presents a discussion of the findings in light of the extant research literature, highlighting this research's contributions.

6.4.3 Interpretation

Information systems can support coordination mechanisms aimed at mitigating congestion. This research found that both information sharing and digital tools could support congestion mitigation efforts subject to several factors. In terms of information sharing, two factors were of key importance: initiating information sharing and the continuation and impact of information sharing practices.

The initiation of information sharing was contingent on reducing information asymmetry on the information available in the supply chain. It was evident from the exploration interviews that significantly more data and information were available in the supply chain, within individual organisations, than perceived by the participants. The researcher had the opportunity to interact with participants in multiple organisations and form an overall, relatively complete picture of the information collected and sometimes shared. It became evident that information asymmetry between participants was, at times, maintained for competitive reasons. Whilst these practices were generating some costs, the participants appeared to weigh this cost against the perceived competitive advantage they were obtaining.

The second layer of information asymmetry regarded the information available in the supply chain. The issue here was not whether information can be shared, but whether participants were aware that information was being collected and was available for sharing. In several instances during the interviews, the participants expressed their availability to share information if they would be asked the '*right questions*'. Naturally, this created a conundrum for the participants, as asking the right questions was contingent on knowing whether information exists which was itself contingent on asking the right questions. The workshops helped participants better understand the information collected and available in other organisations. In Case A, the workshops provided an opportunity for some participants to agree on lowering information asymmetry on information that was previously considered as providing some competitive advantage.

The continuation and impact of information shared appeared highly dependent on the participants' behaviours in response to the information shared. One of the most frequent expectations expressed by participants regarding information sharing was feedback. While feedback does not necessarily strike as an essential aspect of information sharing, it was evident that, in some cases, the lack of it could cause frustration. As frustration builds up, it is expected that information sharing may diminish, cease, or be replaced with more coercive mechanisms. Another critical behaviour was the use of the information shared. Thus, if the information shared was not actioned on, it was unlikely to generate significant operational impact. The verbalisation of behavioural expectations during the workshops and the clarification of behaviours in response to the information sharing were two elements that facilitated the establishment of information sharing practices and contributed to the continuation of such practices.

The researcher suspects that as the number of participants involved in information sharing increases, information sharing challenges may also increase. This is evidenced by the fact that in the case studies with many participants, and especially multiple contractors, it was generally difficult to arrange suitable times for all participants to attend. In Case B, where a large proportion of contractors participated, a second iteration of the design workshop did not occur, primarily because many participants were unable to attend. These challenges related primarily to synchronous information sharing situations. Asynchronous information sharing, particularly facilitated by digital tools, may mitigate some of these challenges. However, the use of digital tools likely includes an element of trust that is more easily developed during face-to-face interactions. Therefore, approaching information sharing as a synchronous process which can be subsequently digitally-enabled may provide the most effective approach.

The simulation modelling revealed that a TAS was one of the most effective approaches to mitigate congestion. A TAS is a digital platform that allows terminal users and terminal operators to communicate with one another, asynchronously, their operational plans. The terminal operator can communicate the expected terminal capacity in terms of equipment and staffing. The terminal users can communicate to the terminal operator their planned operational times. Importantly, an appointment system may allow terminal users to see de-identified or aggregate information of other users' operational expectations and adjust their operations accordingly. The exploratory data analysis and the qualitative analysis highlighted the negative impact limited coordination had on congestion. A TAS's effectiveness with respect to congestion mitigation is likely associated with the fact that appointment systems' functions are conducive to supporting coordination.

This research found that the usage patterns of existing digital tools were primarily oriented towards monitoring and compliance and, on rare occasions, to support operational decisions. The data generated by tools implemented in the case study organisations were rarely studied or analysed, thus rarely transformed into information. The situations where data was analysed and transformed into information generally pertained to evaluating whether operational and compliance thresholds had been exceeded (i.e. maximum storage capacity or weight compliance limits). However, participants often expected that new digital tools could generate operational improvements. This expectation did not appear to be accompanied by an understanding through which the novel tools or the data they generate would contribute to operational improvements. In two of the cases, participants engaged in lengthy discussions of a novel digital tool, eDockets, that was considered useful in addressing the challenges they were facing, including congestion. The researcher suspected that the tool functions, providing real-time visibility of trucks' whereabouts and digitalising the truck weighing process, were not necessarily aligned with the factors that contributed to the appearance of congestion. Therefore, it was likely that implementing such digital tools, although providing some benefits, would fail to help mitigate congestion.

The simulation model scenario analysis illustrated how the misalignment between a digital tool's function and the factors causing a problem may fail to help mitigate congestion. The weigh-bridge automation could improve the efficiency of the unloading operation and, in some cases, reduce the truck turnaround times average by up to 20%. Ostensibly, such improvements in the unloading operation's efficiency could reduce congestion at the terminal. However, while the truck turnaround time average may be reduced, the truck turnaround distribution retains its shape. Therefore, the significant waiting times and uncertainty associated with congestion remain in the system even if the average turnaround time decreases. Although potentially improving efficiency, weigh-bridge automation may fail to contribute to congestion mitigation.

The next sub-section presents a discussion of the findings in light of the extant research literature, highlighting this research's contributions.

6.4.4 Discussion

This research has highlighted the usefulness of exploring the interaction between the social and technical aspects of information systems in understanding their role in bulk cargo marine terminals and their associated supply chains.

The potential of digital tools, such as appointment systems and automation technology, to contribute to congestion mitigation, was highlighted using simulation modelling. The evidence provided in this research in terms of the impact of appointment systems on truck turnaround times and congestion reduction aligns with findings from the research literature (Huynh, 2009; Ramírez-Nafarrate *et al.*, 2017; Li *et al.*, 2018; Riaventin and Kim, 2018; Torkjazi, Huynh and Shiri, 2018). This research has contributed to the research literature by highlighting the effectiveness of appointment systems against other approaches in a range of throughput scenarios. The simulation model scenario analysis has revealed that automation technology, while reducing operational times, has a relatively limited effect on congestion per se. Importantly, this research has highlighted that both user behaviours and the appointment system parameters impact the effectiveness of the TAS. Thus, increased system usage and punctuality lead to a greater reduction in truck turnaround times. This finding is also confirmed by other researchers (e.g. Ramírez-Nafarrate *et al.*, 2017; Li *et al.*, 2018).

Much of the academic research literature investigating the role of information technology in supply chain consider technology as a communication and automatization enabler and ultimately as a driver for increased organisational efficiency and competitive advantage (van Baalen, Zuidwijk and van Nunen, 2008; Heilig and Voß, 2017). The evidence produced in this research aligns with the literature findings in terms of the impact of digital tools – terminal appointment systems and automation technology – on the efficiency of operations by reducing truck turnaround times. However, this research has shown that improving operational efficiency is not necessarily equivalent to addressing congestion.

In a similar vein, evidence in this research point towards the fact that participants appear to view technology as a driver for efficiency and operational performance. This perspective embodies the assumptions of technological determinism (Cascio and Montealegre, 2016). Similarly, the participants' perspectives appear to be consistent with the (implicit) assumptions in the technology research literature. However, the participants' perspectives did not appear to be grounded in evidence from their experience with new or existing digital tools. Thus, existing information technology was generally used to monitor operations and compliance. The participants were aware that new technology tools considered for implementation failed to produce the expected outcomes yet persisted in their belief. This finding highlights the importance of considering the way in which technology is appropriated by users when exploring its impact on organisations.

This research has provided evidence that information sharing, which supported the coordination mechanisms established by the stakeholders, had a positive impact on reducing truck congestion. Information sharing and technology are two mechanisms that can support supply chain coordination (Vosooghidizaji, Taghipour and Canel-Depitre, 2020). This finding supports the results in the academic literature regarding the positive impact of information sharing with regards to organisational and supply chain efficiency (Yigitbasioglu, 2010; Fawcett *et al.*, 2011; Huo, Han and Prajogo, 2016). Importantly, this finding also provided evidence that congestion mitigation can also be undertaken by the supply chain stakeholders, not only by the terminal operators.

This research also highlighted the importance of reducing information asymmetry between stakeholders to facilitate the emergence of novel information sharing patterns. The research literature investigating information sharing tends to be primarily descriptive of the antecedents, barriers, dimensions and outcomes of information sharing (Fawcett *et al.*, 2007; Mora-Monge *et al.*, 2019). Although understanding these facets of information sharing provides important organisational insights, in this research, these insights were of limited use in understanding how novel information sharing emerge between stakeholders. In this research, reducing information asymmetry between participants about the information collected in the supply chain was one factor facilitating the emergence of information sharing. This finding aligns with Shaw, Grainger and Achuthan (2017) observation that port stakeholders "*never considering sharing information in the first place*" and highlights a potential explanation for not considering to share information – not knowing what and whether the information is relevant for other participants. Thus, information sharing may arise to address information asymmetries between stakeholders (Connelly *et al.*, 2011). Information sharing may also emerge as a consequence of the reduction of information asymmetry about information in the supply chain.

This research's findings revealed that information sharing was generally accompanied by behavioural expectations from the recipient, the most frequent being that of providing feedback. In other cases, new decisions had to be taken based on the information shared (i.e. when sharing vessel schedules, people observed clashes of vessel arrivals and therefore on or more parties had to reschedule a vessel). It was likely that this expectation was not shared with or understood by the information recipient. However, if the receiver of information provided no feedback, this created frustration and lowered the willingness to share information further. This finding highlights the importance of considering the social aspects of information sharing, particularly its meaning attributed to the information being shared and its use. Thus, a deterministic perspective on information sharing in which adding information to the system is expected to impact the system may fail to account for the fact that the information needs to be understood by the recipients and integrated into the stakeholders’ behaviours to make a difference.

The next section discusses the summary reflections of this chapter.

6.5 Summary Reflections

This chapter presents the six key findings emerging from the interpretation of the analyses presented in the previous chapter.

This research has highlighted that social, technical and behavioural factors pertaining to the terminal, the marine- and landside supply chain interact to facilitate the appearance of landside congestion. The factors uncovered in this research include limited coordination, the interdependence of supply chain operations, misaligned incentives, lack of supply chain flexibility, infrastructure limitations, disruptions and performance expectorations. Furthermore, the plurality of perspectives and related behavioural responses on congestion factors and their interrelationships is in itself a factor affecting congestion (***KF-1.***). Consequently, congestion, particularly with increased recurrence, can impact supply chain competitiveness and resilience (***KF-2.***).

The complexity of congestion in terms of participants, perspectives and interrelationships between various factors means that a holistic approach is required to capture the nature of the problem. In this sense, this research has shown that the participatory design approach utilised in this research effectively enhanced understanding and generated congestion mitigation mechanisms at a supply chain level (***KF-3.***). When analysing and interpreting data regarding congestion, this research has found that the average truck turnaround or waiting time, used in isolation from other indicators and measures, may misrepresent congestion (***KF-4.***).

In terms of the role information systems can play in understanding and mitigating congestion, this research has provided evidence that information systems supported the supply chain coordination mechanisms can, in fact, contribute to congestion mitigation. This research has uncovered that information sharing initiation was partially contingent on addressing information asymmetry between participants and a mutual definition of the behavioural responses expected of each party following information sharing (***KF-5.***). Finally, in terms of digital tools, this research has highlighted that the participants' conviction of the expected benefits of digital tools to mitigate congestion were not grounded in evidence or a clear understanding of the mechanisms through which information systems would address the issue (***KF-6.***).

This research has also highlighted the value of using multiple case studies and a mixed-method approach to better understand a complex, multi-faceted phenomenon such as landside congestion. Importantly, through the involvement of the supply chain stakeholders in understanding congestion, situated mitigation mechanisms emerged. These mechanisms were integrated into business practices and helped ameliorate the impact of congestion. The multiple case studies participatory design approach which combines qualitative and quantitative data collection, and analysis techniques provides a series of opportunities for landside congestion and potentially other aspects pertaining to bulk cargo supply chains.

The next chapter presents the conclusions of this research.

Chapter 7 Conclusions

7.1 Introduction

The previous chapter presented discussed and interpreted the six key findings of this research in relation to the three research questions.

This chapter presents a conclusion of this research. The structure of this chapter is as follows:

- Section 7.2 presents a synthesis of the key finding and discusses the contributions of this research at a substantive, methodological and conceptual levels.
- Section 7.3 discusses the limitations of this research.
- Section 7.4 presents potential avenues for future research.
- Section 7.5 provides the summary reflections of this chapter.

7.2 Key Findings and Contributions

This research was initiated to explore landside congestion factors and mitigation mechanisms in bulk cargo marine terminals for forest products. Furthermore, the role of information systems in better understanding and mitigating congestion was also explored. This led to the emergence of three research questions:

RQ-1. *What congestion factors, their interrelationships, and implications can be identified and understood?*

RQ-2. *How can a holistic understanding of landside congestion and mitigation mechanisms at bulk cargo marine terminals for forest products be generated?*

RQ-3. *What is the role of information systems in understanding and mitigating landside congestion at marine terminals for forest products?*

This research sought to answer the research questions based on three case studies and using an adapted participatory design approach. The key findings that emerged from this research were:

KF-1. Social, technical and behavioural factors pertaining to the terminal, the marine- and landside supply chain interact to facilitate the appearance of landside congestion. Therefore, congestion can be considered an 'emergent' property of intersecting supply chains.

KF-2. Congestion, particularly with increased recurrence, affects the costs, compliance and fatigue risks of truck operators as well as creating operational uncertainty and the generation of significant frustration for participants across supply chains.

KF-3. The participatory design approach utilised in this research enhanced the researcher's and participants' understanding of congestion and facilitated the emergence of contextually relevant congestion mitigation mechanisms.

KF-4. Conventional measures of congestion (e.g. average truck turnaround times), used in isolation from other indicators, tend to misrepresent congestion.

KF-5. Information systems can contribute to better understanding and mitigation of congestion.

KF-6. The participants' perceptions of the expected benefits of digital tools to mitigate congestion were not grounded in evidence or a clear understanding of the mechanisms through which information technology would address congestion.

This research has generated a series of contributions to the current research literature at, substantive, methodological and conceptual level.

7.2.1 Substantive

At a **substantive** level, this research provides a detailed, in-depth exploration of three case studies centred on bulk cargo marine terminals for forest products and their associated supply chains experiencing landside congestion. For each of the case studies included, the researcher provided extensive data analysis and recommendations report to organisations involved in the supply chain. A discrete-event simulation model of a bulk cargo marine terminal was also constructed and used to evaluate the impact of different congestion mitigation scenarios. In one case, the report as a guide for the participants to improving operations and manage congestion.

This research has also found that the implications of congestion can be felt at a supply chain level. Congestion can affect the competitiveness of the supply chains against other, similar chains. Similarly, this research has also found that congestion can affect the supply chain's resilience through ongoing system strain.

The role of information systems in congestion mitigation was also empirically illustrated. Thus, information sharing that supported the coordination mechanisms instantiated by the participants was an important factor in reducing truck turnaround times and congestion. This research found that information sharing initiation was partially contingent on the level of information asymmetry and provided evidence that a reduction in asymmetry can facilitate the emergence of new information sharing mechanisms. Furthermore, the establishment and communication of behavioural expectations was an important factor supporting the continuation of information sharing.

This research also provided a detailed description of the Australian forest products export supply chain and identified aspects that should be considered in the research design. These include the regulatory framework under which the supply chain operates, the supply chain structure and competitors.

7.2.2 Methodological

At a **methodological** level, this research has shown the usefulness of the participator design approach in better understanding congestion, mitigation approaches, and information systems' role in this context. This research has contributed to the research literature investigating congestion and its management through a methodology that broadens the investigation scope to include a large proportion of the supply chain and explores the phenomena using qualitative and quantitative data collection and analysis techniques. The methodology employed effectively generated mutual understanding and a common vocabulary between participants in the case studies, and ultimately led to the emergence and adoption of congestion mitigation designs.

In synthesizing the insights developed in this research, a framework for participatory mitigation of landside congestion emerged. This framework can be used as a sensitising device for researchers on approaching congestion mitigation in bulk cargo marine terminals. This framework also highlights the links between the congestion factors and the mitigation mechanisms and presents an approach for the development of contextually-adapted mitigation mechanisms. Two of the most influential and highly cited papers in the domain of landside congestion management are empirical investigations (Giuliano & O'Brien, 2007; Morais & Lord, 2006). The issues highlighted by these papers regarding the ineffectiveness of appointment systems and other congestion mitigation methods in practice have been the primary driver for this work. Although these papers are more than a decade old, the extant research literature has, to date, failed to answer the question of how theoretical benefits derived from congestion mitigation be achieved practice. The participatory mitigation of landside congestion framework developed in this research represents this work's contribution to this body of knowledge.

The breadth of the qualitative data collection and the coding process drawing on the principles of grounded theory analysis of the qualitative data proved useful in revealing novel insights regarding congestion. The data collection included a range of stakeholders involved in the supply chain. Thus, the analysis revealed novel insights regarding the range of congestion factors that pertained to the terminal and the supply chains. Interestingly, the analysis also revealed differences in perspectives amongst participants regarding congestion factors and mitigation strategies.

The use of qualitative and quantitative data collection and analysis allowed for triangulation of results and highlighted a series of aspects with regards to congestion: differences between the importance participants attributed to terminal infrastructure in relation to congestion and the impact it had on congestion; differences between the importance attributed by participants to coordination and its impact on congestion and; differences in expectations and interpretation of measures of congestion.

The discrete-event simulation model took advantage of novel data sources and model capabilities to generate relevant insights for the participants. Thus, the model was constructed using overlapping geo-positioning data from trucks and truck arrival data spanning more than three months. The resulting model was a relatively robust and accurate representation of terminal operations. Furthermore, the model was used to evaluate the impact of various congestion factors and the effectiveness of multiple congestion mitigation approaches.

Importantly, the workshops that included supply chain participants were useful in generating mutual understanding and facilitating the development of situated approaches to mitigate congestion. The participants developed mechanisms supported by information sharing which were implemented and helped mitigated congestion. Furthermore, partially due to the simulation modelling results, the terminal operator in one case study, with the participants' support, commenced the procurement process for a terminal appointment system solution.

The participatory design approach used in this research was a useful tool to investigate a phenomenon beyond organisational boundaries to generate a holistic understanding both for the researcher and the participants themselves and provided an environment conducive to the emergence of designs to address the phenomenon.

7.2.3 Conceptual

At a **conceptual** level, this research has revealed the usefulness of a holistic, supply chain perspective for better understanding the social and technical factors conducive to the appearance of congestion and the consequences this phenomenon has on the affected organisations and individuals. This research also explores the role of information systems in relation to congestion factors.

This research contributed to the research literature by highlighting that a more holistic approach, integrating the sea-, terminal and landside elements of the chain can reveal a broad range of congestion factors. A model of congestion factors interacting at the different levels of analysis emerged from aggregating the research of this applied research. The model categorises factors into behavioural, social, and technical factors across the three different levels of analysis, from individuals within organisations, organisations within supply chains and organisations between supply chains converging at the same facility. The congestion factors identified in this research were: limited coordination of logistics activities, interdependence with other supply chain operations, misaligned incentives, inadequate terminal infrastructure, operational disruptions and lack of supply chain flexibility. Importantly, this research has also highlighted that across the range of supply chain stakeholders, perceptions on congestion and contributing factors vary significantly. Therefore, this research questions the assumption landside congestion in marine terminals is a terminal problem that falls under the responsibility of terminal operators.

This research has contributed to the research literature by defining congestion as "*An emergent symptom of logistics systems, characterised by higher-than-expected delays, generally manifesting at marine terminals, caused by a plurality of factors and their interactions and a multitude of stakeholders' perspectives and associated individual response behaviours*". This definition complements existing definitions of congestion that are less useful in understanding and exploring the phenomenon of congestion.

The importance of understanding the congestion factors and aligning the congestion mitigation approaches, particularly those related to digital tools was also highlighted in this research. The effectiveness of various congestion mitigation methods was compared using simulation modelling. This comparison highlighted that additional infrastructure was often less effective than improved coordination using appointment systems. This research has also provided evidence that the appointment system's effectiveness is related to the congestion factor it helps mitigate. Thus, in this research, a primary congestion factor was the limited coordination which can be effectively addressed using an appointment system. The simulation model has also provided evidence that automation technology can improve operational efficiency and reduce truck turnaround times but may have limited impact on waiting times and therefore, congestion.

The next section discusses the limitations of this research.

7.3 Limitations of Research

Limitations are an inherent component to research. Three main categories of limitations may have affected this research: scope limitations, research bias and generalisability limitations.

This research's scope was intentionally limited to one type of marine terminal and one type of product to reduce the potential confounding effects of various terminal and industry types. Nonetheless, additional case studies could shed more light on the socio-technical factors affecting and interacting in bulk cargo terminals regarding congestion. Quantitative data availability in cases B and C limited replicating the discrete-event simulation model. Qualitative and quantitative data (un)availability significantly limited the exploration of maritime-related factors that could have played a role in landside congestion. Finally, there were some differences in the length of the researcher's exposure with each case study field site and the participants due to time and cost constraints. Additional researcher exposure to the case study field sites could have potentially increased the depth of the exploration.

Research bias may be introduced both by the researcher and the participants. The researcher's perceptions and prior knowledge may have influenced the data collection, analysis and interpretation. The participants' reactions to the interview process, their involvement in the workshops may have also been sources of bias. The researcher observed differences in the participants' willingness to engage in the design process and subsequently implement the emerging designs. The research design attempted to control for potential biases both from the researcher and the participants. Therefore, the research design included both qualitative and quantitative data and a diverse range of participants in an attempt to limit bias (Miles and Huberman, 1994).

Finally, the case study participatory design approach adopted in this research presents advantages and limitations. One limitation is that the approach and the results generated have limited statistical generalisability. Statistical generalisability appeared to be one of the main research goals in the supply chain and landside congestion management research literatures. Nonetheless, the approach adopted in this research opens up for theoretical generalisability and the instantiation of change in the cases explored. As evidenced in Section 5.4.1, a less structured version of the participatory design approach in this research has been used by the terminal operator representatives in Case A to address landside congestion in another terminal belonging to the same company.

The participatory design approach adopted in this research resembles, on the surface, typical management and information technology consultancy approaches. However, this research significantly differs from consultancy-type approaches in terms of aims, general approach and outcomes. This research aimed to contribute to the body of knowledge on landside congestion management. This permitted the researcher a degree of neutrality when exploring congestion and mitigation options Conversely, typical consultancy approaches aim to address (often a-priori) defined objectives by the consultants' employer. This research's methodology was constructed through an extensive literature review building on previous work and strengths of different methods (e.g. simulation modelling, workshops or exploratory data analysis). In contrast, consultant approaches may be less complex and adapted. Furthermore, technology products developed by consultancy companies may be part of the approach or solution irrespective of the nature of the problem. The approach in this research took place over several years as opposed to several months or weeks in consultancy, allowing the researchers to gain an in-depth understanding of the participant companies' operations. The research outcomes consisted of decision-making models and methods for the participants to enhance their understanding of landside congestion management irrespective of the organisation they represent. Typically, consultancy outcomes are specifically targeted for the employing entity.

This research's findings may act as sensitising devices for other researchers conducting studies in supply chain and maritime terminals.

The next section presents several potential avenues for future research.

7.4 Future Research

This research has opened up additional areas for future research in supply chains, landside congestion management and participatory design.

This research has generated a model of congestion factors and a participatory framework for congestion mitigation which can be used by researchers in similar settings. Thus, future research can explore other types of marine terminals and supply chains to uncover similarities and differences regarding congestion factors and interactions. Given that a large proportion of the research literature on landside congestion management centres on container terminal, future research can explore congestion factors, mitigation, and information systems' role concerning containerised flows. This research has focused extensively on factors pertaining to the landside logistics flows. Future research can investigate the interplay between marine and landside flows and its impact on congestion in greater detail. Finally, the simulation modelling can be extended to include additional factors pertaining to the landside supply chains – such as production and truck scheduling – as well as maritime factors – such as vessel arrivals.

This research has illustrated the usefulness in conceptualising congestion as a '*wicked*' problem to generate a holistic understanding of the socio-technical factors interacting in supply chains. Future research can use the theoretical lens of '*wicked*' problems to sensitise researchers towards the multitude of facets of issues in modern supply chains.

This research highlighted that the participants' perceptions towards technology were consistently pointing towards efficiency improvements. These perceptions persisted even in the face of evidence pointing towards the opposite relation. The participants' perceptions appear aligned with technological determinism, a prevalent perspective in academia as well as practice. The researcher speculated on some of the reasons which may have led to the formation of such perceptions. However, a detailed investigation of these reasons was outside the scope of this study. Nonetheless, given the prevalence of digital tools in modern supply chains, future research can empirically explore practitioners' perceptions of technology and the reasons for their formation.

The next section discusses the summary reflections of this chapter.

7.5 Summary Reflections

In conclusions, this research has explored the role of information systems in understanding and mitigating landside congestion in bulk cargo marine terminals for forest products. This research utilised a multiple case studies participatory design approach structured in three stages to generate a holistic understanding of socio-technical factors contributing to the appearance of congestion and the role of information systems in understanding and addressing congestion.

This research has contributed to the body of knowledge at a substantive, methodological and conceptual levels. At a substantive level, this research provides a detailed, in-depth exploration of three case studies centred on bulk cargo marine terminals for forest products and their associated supply chains experiencing landside congestion. At a methodological level, this research has shown the usefulness of the participator design approach in better understanding congestion, mitigation approaches, and information systems' role in this context. This research has contributed to the research literature investigating congestion and its management through a methodology that broadens the investigation scope to include a large proportion of the supply chain and explores the phenomena using qualitative and quantitative data collection and analysis techniques. At a conceptual level, this research has revealed the usefulness of a holistic, supply chain perspective for better understanding the social and technical factors conducive to the appearance of congestion and the consequences this phenomenon has on the affected organisations and individuals. This research also explored the role of information systems in relation to congestion factors.

This research has laid the foundations for future research in exploring congestion from a holistic perspective and more broadly supply chain challenges.

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Appendices

Appendix A. Interview and Workshop Information Sheet

An analysis of timber and wood products transport operations and related industrial supply chains

Information sheet for interview participants

1. Invitation

You are invited to participate in our study that investigates timber and wood products transport operation challenges. The research is carried out by Mihai Neagoe, as a PhD candidate in the School of Engineering and ICT and Associate Professor Paul Turner in the School of Engineering and ICT within the University of Tasmania as Chief Investigator.

This study is being conducted in partial fulfillment of a PhD for Mihai Neagoe as a student under the supervision of Associate Professor Paul Turner.

2. What is the purpose of this study?

The purpose of this study is to investigate timber and wood products transport operations in a number of Tasmanian and Victorian supply chains. To achieve this goal, we are interviewing people in positions related to the timber and wood product flows from a number of companies to understand the way the system works at the moment, the areas where challenges arise, and possible improvements.

3. Why have I been invited to participate?

You are invited to participate in this study because we have identified you as potentially having valuable information regarding timber and wood products transport operations and the challenges around the current system operations.

Participation is voluntary and there are absolutely no consequences should you decide not to participate in this study.

4. What will I be asked to do?

You will be asked to mention your name and role within the company you work and questions regarding your current responsibilities and daily workflow. Other questions are related to the challenges you are facing with respect to the woodchip supply chain operation and the areas that could be improved to help your daily work. There is no requirement to answer all questions and the level of detail that you want to go to is entirely up to you.

During the interview, we will be making notes and audio-recording the interviews. We are interested in conducting the discussions in three stages, a baseline meeting, a preliminary analysis meeting and a validation meeting. Each meeting is expected to take no more than 45 minutes and will take place in the office or some other place mutually agreed on. During the second and third meetings, we will discuss with you the information we have already collected and present our current understanding of the processes, challenges, and areas where improvements may be most suitable. You will then have the possibility to amend or clarity items.

You may also be invited to participate in focus groups involving multiple participants that operate within the same business environment. These focus groups aim to align collective knowledge and understanding regarding the problem space to facilitate the design of an approach to alleviate identified issues. Between 6 and 10 focus groups are expected to be conducted, each lasting approximately 1 hour. The meetings will be facilitated by the research team, audio-recorded, transcribed and notes will be taken during discussions. Following each focus group, audio recordings and transcripts can be reviewed upon request.

5. Are there any possible benefits from participation in this study?

We expect that the information you provide will help us identify bottlenecks in current operations and propose solutions that can enhance the efficiency and effectiveness of the timber and wood products transport operations.

6. Are there any possible risks from participation in this study?

We do not foresee any possible risks from participation in this study.

7. What if I change my mind during or after the study?

In the event you change your mind you can let us know at any time before the study is published without providing an explanation for your decision. The audio recording of our interview will be immediately erased and there will be no mention made in the study of your involvement. There are no consequences if you decide to withdraw at any time.

8. What will happen to the information when this study is over?

All data collected will be treated in a confidential manner and will be shared only between researchers in this research group at the University of Tasmania. There will be no direct extract or quote taken from an audio interview and published in the study, as much as possible, all data will be summarised and presented in the company or general context.

After the study is completed, all physical documents and digital data will be handed to responsible persons at the School of Engineering and ICT and it will be deleted by the CIS administrator when archive time is completed.

9. How will the results of the study be published?

Findings will become part of the PhD dissertation of Mihai Neagoe which will be published in the University of Tasmania Thesis repository at the time of completion. The expected date of the thesis publication is January 2020.

10. What if I have questions about this study?

If you have any questions about the study feel free to contact us at any time on +61 3 6226 6240 or +61 3 6226 2135 or email Paul.Turner@utas.edu.au and Mihai.Neagoe@utas.edu.au.

This study has been approved by the Tasmanian Social Sciences Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study, please contact the Executive Officer of the HREC (Tasmania) Network on +61 3 6226 6254 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. Please quote ethics reference number H0016718.

This information sheet is for your record. Together with this information sheet you will have received two copies of the consent form. Please sign both of them. One of them is for your records as well. By signing the consent form, you agree to take part in this study in the conditions mentioned above. Thank you.

Appendix B. Interview and Workshop Consent Form

An analysis of timber and wood products transport operations and related industrial supply chains

1. I agree to take part in the research study named above.
2. I have read and understood the Information Sheet for this study.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves interviews in three stages each lasting for approximately 45 minutes. Interviews are audio-recorded, and notes are taken during each interview. In each interview stage, prior information can be reviewed and changed. This can be done up until the publication date of the study which will be approximately 3 months after the interviews take place.
5. I understand that I may be asked to participate in focus groups involving multiple participants that operate within the same business environment. Between 6 and 10 focus groups are expected to be conducted, each lasting approximately 1 hour. The meetings will be facilitated by the research team, audio-recorded, transcribed and notes will be taken during discussions. Following each focus group, audio recordings and transcripts can be reviewed upon request.
6. There are no foreseeable risks of participation in this study
7. I understand that all research data will be securely stored on the University of Tasmania premises for five years from the publication of the study results and will then be destroyed unless I give permission for my data to be stored in an archive.

   I agree to have my study data archived.

   Yes ☐ No ☐
8. Any questions that I have asked have been answered to my satisfaction.
9. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research. The data will not be shared with anyone else outside the research group at the University of Tasmania.
10. I understand that the results of the study will be published so that I cannot be identified as a participant. Findings will become part of the PhD dissertation of Mihai Neagoe which will be published in the University of Tasmania Thesis repository at the time of completion. The expected date of the thesis publication is January 2020.
11. I understand that my participation is voluntary and that I may withdraw at any time without any effect.

    If I so wish, I may request that any data I have supplied be withdrawn from the research until the research publication date.

Participant's name: ____

Participant's signature: ____

Date: ____________________

Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked.

☐ The participant has received the Information Sheet where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

Investigator's name: ____

Investigator's signature: ____

Date: ____________________

Appendix C. Additional Details on Quantitative Data Collection

Table 16 contains a weigh-bridge extract from Case C.

Table 16 Case C - Weigh-Bridge Data Extract

Date	Op. Code	Truc k ID	Gross Weight (GMT)	Tare Weight (GMT)	Net Weight (GMT)	Time in (Gross) (hh:mm:ss)	Time Out (Tare) (hh:mm:ss)	Unloading Time (hh:mm:ss)
01/02/2018	B018	2	66.95	20.88	46.07	05:42:57	06:40:38	00:57:41
01/02/2018	B018	3	68.55	23	45.55	06:50:18	07:06:04	00:15:46
01/02/2018	B018	2	67.3	20.78	46.52	09:08:36	09:32:40	00:24:04
01/02/2018	B018	3	68.3	22.94	45.36	10:02:15	10:22:12	00:19:57
01/02/2018	B018	2	67.25	20.76	46.49	11:55:25	12:21:55	00:26:30
01/02/2018	B018	3	67.85	22.82	45.03	13:09:07	13:48:52	00:39:45
01/02/2018	B018	2	66.55	20.68	45.87	14:51:34	15:19:37	00:28:03
01/02/2018	B018	3	67.85	22.76	45.09	16:12:49	16:32:22	00:19:33
01/02/2018	B023	4	67.95	21.14	46.81	10:59:42	11:16:10	00:16:28
01/02/2018	B023	5	67.9	22.36	45.54	11:52:29	12:17:08	00:24:39
01/02/2018	B023	4	68.2	21.04	47.16	13:41:35	14:19:04	00:37:29
01/02/2018	B023	5	67.95	22.24	45.71	14:14:49	14:40:44	00:25:55
01/02/2018	B023	5	67.55	22.24	45.31	14:49:03	15:13:58	00:24:55

Figure 57 shows the Geo-positioning software portal home screen.

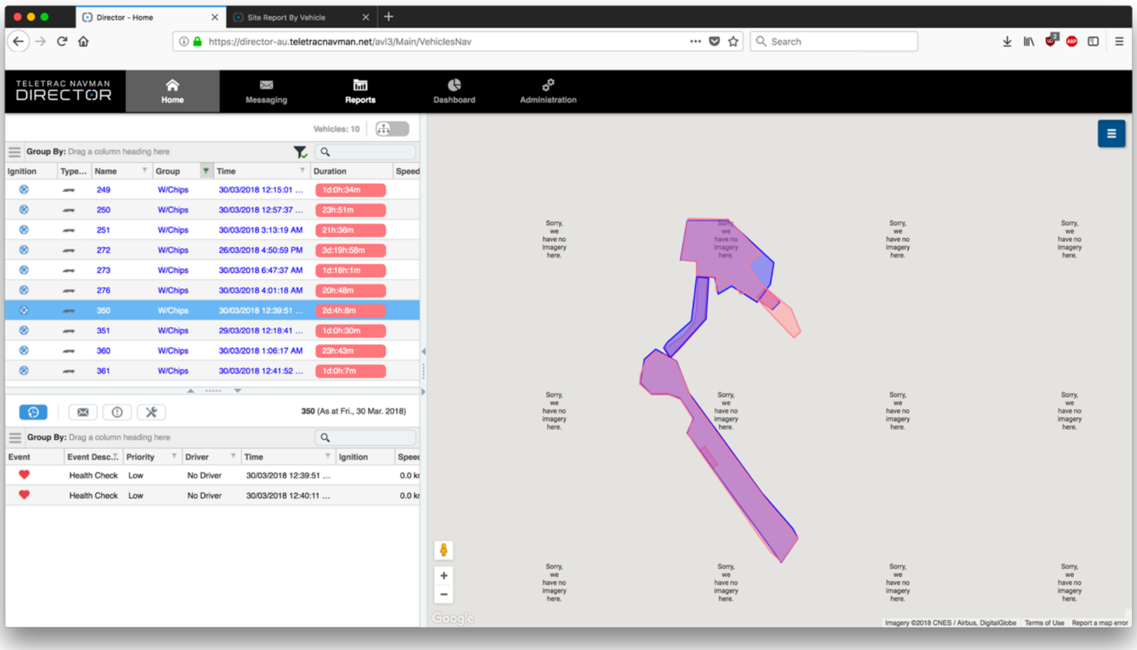
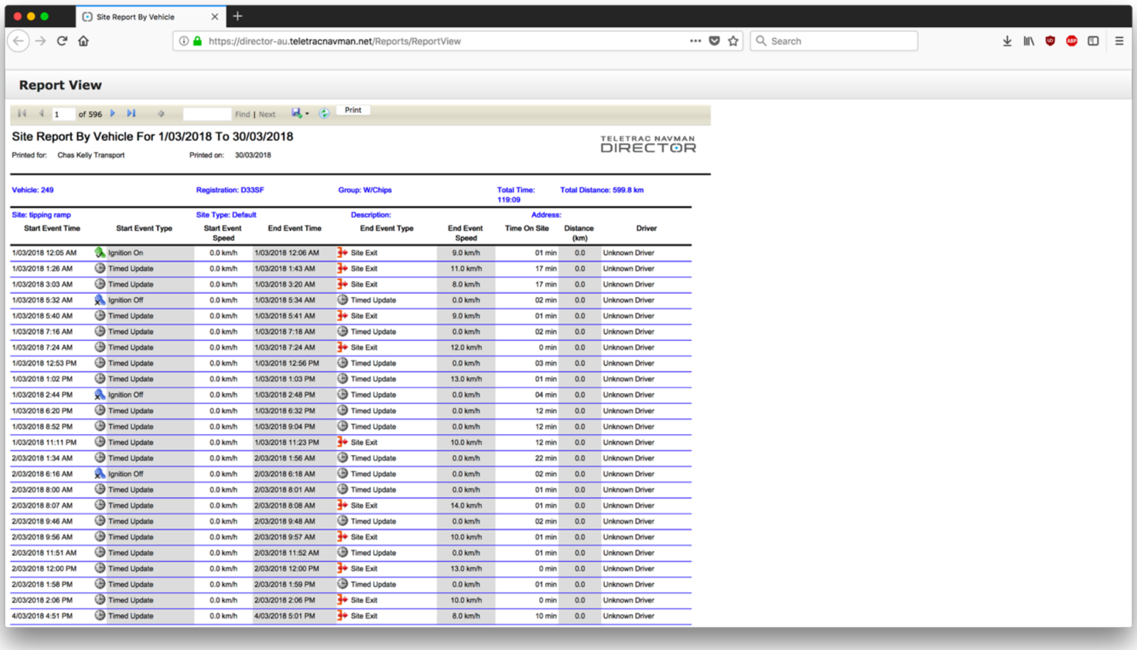


Figure 57 Case A - GPS Software Provider Portal for Geo-Fence Data Download

Figure 58 shows an extract of geo-fence data output from the GPS software provider portal.



Site Report By Vehicle

https://director-au.teletracnavman.net/Reports/ReportView

Report View

1 of 596 Find | Next Print

Site Report By Vehicle For 1/03/2018 To 30/03/2018

TELETRAC NAVMAN DIRECTOR

Printed for: Chas Kelly Transport Printed on: 30/03/2018

Vehicle: 249 Registration: D33SF Group: W/Chips Total Time: 119:09 Total Distance: 599.8 km

Site: tipping ramp Site Type: Default Description: Address:

Start Event Time	Start Event Type	Start Event Speed	End Event Time	End Event Type	End Event Speed	Time On Site	Distance (km)	Driver
1/03/2018 12:05 AM	Ignition On	0.0 km/h	1/03/2018 12:06 AM	Site Exit	9.0 km/h	01 min	0.0	Unknown Driver
1/03/2018 1:26 AM	Timed Update	0.0 km/h	1/03/2018 1:43 AM	Site Exit	11.0 km/h	17 min	0.0	Unknown Driver
1/03/2018 3:03 AM	Timed Update	0.0 km/h	1/03/2018 3:20 AM	Site Exit	8.0 km/h	17 min	0.0	Unknown Driver
1/03/2018 5:32 AM	Ignition Off	0.0 km/h	1/03/2018 5:34 AM	Timed Update	0.0 km/h	02 min	0.0	Unknown Driver
1/03/2018 5:40 AM	Timed Update	0.0 km/h	1/03/2018 5:41 AM	Site Exit	9.0 km/h	01 min	0.0	Unknown Driver
1/03/2018 7:16 AM	Timed Update	0.0 km/h	1/03/2018 7:18 AM	Timed Update	0.0 km/h	02 min	0.0	Unknown Driver
1/03/2018 7:24 AM	Timed Update	0.0 km/h	1/03/2018 7:24 AM	Site Exit	12.0 km/h	0 min	0.0	Unknown Driver
1/03/2018 12:53 PM	Timed Update	0.0 km/h	1/03/2018 12:56 PM	Timed Update	0.0 km/h	03 min	0.0	Unknown Driver
1/03/2018 1:02 PM	Timed Update	0.0 km/h	1/03/2018 1:03 PM	Timed Update	13.0 km/h	01 min	0.0	Unknown Driver
1/03/2018 2:44 PM	Ignition Off	0.0 km/h	1/03/2018 2:48 PM	Timed Update	0.0 km/h	04 min	0.0	Unknown Driver
1/03/2018 6:20 PM	Timed Update	0.0 km/h	1/03/2018 6:32 PM	Timed Update	0.0 km/h	12 min	0.0	Unknown Driver
1/03/2018 8:52 PM	Timed Update	0.0 km/h	1/03/2018 9:04 PM	Timed Update	0.0 km/h	12 min	0.0	Unknown Driver
1/03/2018 11:11 PM	Timed Update	0.0 km/h	1/03/2018 11:23 PM	Site Exit	10.0 km/h	12 min	0.0	Unknown Driver
2/03/2018 1:34 AM	Timed Update	0.0 km/h	2/03/2018 1:56 AM	Timed Update	0.0 km/h	22 min	0.0	Unknown Driver
2/03/2018 6:16 AM	Ignition Off	0.0 km/h	2/03/2018 6:18 AM	Timed Update	0.0 km/h	02 min	0.0	Unknown Driver
2/03/2018 8:00 AM	Timed Update	0.0 km/h	2/03/2018 8:01 AM	Timed Update	0.0 km/h	01 min	0.0	Unknown Driver
2/03/2018 8:07 AM	Timed Update	0.0 km/h	2/03/2018 8:08 AM	Site Exit	14.0 km/h	01 min	0.0	Unknown Driver
2/03/2018 9:46 AM	Timed Update	0.0 km/h	2/03/2018 9:48 AM	Timed Update	0.0 km/h	02 min	0.0	Unknown Driver
2/03/2018 9:56 AM	Timed Update	0.0 km/h	2/03/2018 9:57 AM	Site Exit	10.0 km/h	01 min	0.0	Unknown Driver
2/03/2018 11:51 AM	Timed Update	0.0 km/h	2/03/2018 11:52 AM	Timed Update	0.0 km/h	01 min	0.0	Unknown Driver
2/03/2018 12:00 PM	Timed Update	0.0 km/h	2/03/2018 12:00 PM	Site Exit	13.0 km/h	0 min	0.0	Unknown Driver
2/03/2018 1:58 PM	Timed Update	0.0 km/h	2/03/2018 1:59 PM	Timed Update	0.0 km/h	01 min	0.0	Unknown Driver
2/03/2018 2:06 PM	Timed Update	0.0 km/h	2/03/2018 2:06 PM	Site Exit	10.0 km/h	0 min	0.0	Unknown Driver
4/03/2018 4:51 PM	Timed Update	0.0 km/h	4/03/2018 5:01 PM	Site Exit	8.0 km/h	10 min	0.0	Unknown Driver

Figure 58 Case A - GPS Software Provider Output for Geo-Fence Data

The GPS software provider also collected truck telemetry at 5-minute intervals with regards to the truck's position, speed, direction etc. as well as event data (ignition on, geo-fence entry and exit, hard acceleration and breaking). These data could potentially be analysed to reveal information on driver behaviours, loading and driving durations. However, the researcher considered that the geo-location data particular strength was revealing what was happening in the various unloading stages at the terminal, as these could not be captured with the weigh-bridge data. For this purpose, geo-fences were considered appropriate as these automatically captured truck visit durations in a particular area. Moreover, one truck could generate more than 280 observations per day. Over a fleet of 10 trucks and the 90-days interval of analysis the dataset could potentially reach more than 320,000 observations. The primary constraint in using such a large dataset was the data download speed from the GPS software provider. One week's worth of 5-minute interval data for one truck could take up to 10-minutes to download, with the researcher having to manually reselect the new download. Downloading the data over the entire fleet and timeframe was expected to last more than 3 days. Consequently, geo-fence data covering two geo-fences (weigh-bridge and unloading ramp), a fleet of 10 trucks over a 90-day period were collected.

Table 17 illustrates an example of geo-fence data used. When observations are sorted according to the vehicle and in ascending order of time, the terminal process emerges. Trucks first weigh-in, then are unloaded, then weigh-out. This extract also includes an example of unloading observations which may in fact be fragmented. While it is not possible to unload a truck in one minute, it is reasonable to unload one in 6 or more minutes. If the differences between the same areas are as in this case less than 5 minute, it is reasonable to assume that they represent in fact one observation. A similar pattern was observed with weigh-bridge data.

Table 17 Case A - Geo-Fenced Areas Raw Data

Geo-fenced Area	Vehicle	Entered Time	Exit Time	Time on Site
Weighbridge	1	7/11/17 23:30	7/11/17 23:31	01 min
Unloading	1	7/11/17 23:34	7/11/17 23:44	10 min
Weighbridge	1	7/11/17 23:45	7/11/17 23:49	04 min
Weighbridge	1	8/11/17 00:18	8/11/17 00:19	01 min
Unloading	1	8/11/17 00:41	8/11/17 00:42	01 min
Unloading	1	8/11/17 00:43	8/11/17 00:46	03 min
Unloading	1	8/11/17 00:47	8/11/17 00:51	04 min
Unloading	1	8/11/17 00:55	8/11/17 00:59	04 min
Unloading	1	8/11/17 02:10	8/11/17 02:20	10 min
Weighbridge	1	8/11/17 02:24	8/11/17 02:29	05 min
Weighbridge	1	8/11/17 04:45	8/11/17 04:47	02 min
Unloading	1	8/11/17 05:09	8/11/17 05:18	09 min
Weighbridge	1	8/11/17 05:22	8/11/17 05:26	04 min

In order to speed up the cleansing process, the researcher developed a script to parse the data and identify observations which were likely to be fragmented. The script parses each line of data and verifies the difference between the entry time and exit time of two consecutive observations of the same type of area. If the difference is 5 minutes or less, the *Time on Site* value of the first observation is added to the *On Site (min)* field and the line containing the first observation is subsequently deleted. Once the superfluous data are eliminated, the script parses the data again to identify the potential arrivals and departures. The script classifies a weigh-bridge visit as IN or OUT based on two rules: if the previous site is a weigh-bridge visit, then the current site is a weigh-bridge IN, and if the previous site is an unloading site, then the current site is a weigh-bridge OUT. The resulting data is presented in Table 18.

Table 18 Case A - Geo-Fenced Areas Post-Processing

Geo-fenced Site	Vehicle	Entered Time	Exit Time	Time on Site	On Site (min)
Weighbridge IN	1	7/11/17 23:30	7/11/17 23:31	01 min	1
Unloading	1	7/11/17 23:34	7/11/17 23:44	10 min	10
Weighbridge OUT	1	7/11/17 23:45	7/11/17 23:49	04 min	4
Weighbridge IN	1	8/11/17 00:18	8/11/17 00:19	01 min	1
Unloading	1	8/11/17 00:41	8/11/17 00:42	01 min	removed
Unloading	1	8/11/17 00:43	8/11/17 00:46	03 min	removed
Unloading	1	8/11/17 00:47	8/11/17 00:51	04 min	removed
Unloading	1	8/11/17 00:55	8/11/17 00:59	04 min	12
Unloading	1	8/11/17 02:10	8/11/17 02:20	10 min	10
Weighbridge OUT	1	8/11/17 02:24	8/11/17 02:29	05 min	5
Weighbridge IN	1	8/11/17 04:45	8/11/17 04:47	02 min	2
Unloading	1	8/11/17 05:09	8/11/17 05:18	09 min	9
Weighbridge OUT	1	8/11/17 05:22	8/11/17 05:26	04 min	4

The data were separated according to the site they represented – weigh-bridge in, weigh-bridge out and unloading – and used as input for the distribution fitting process.

Appendix D. Simulation Model - Additional Specification

Table 19 summarises the input data in the distribution fitting process.

Table 19 Case A - Distribution Fitting Data Input Summary

Data	Unload	Weigh-Out	IAT	Truck (I-A)	Truck (II-A)	Truck (I-B)	Truck (II-B)
Min	6	1	0	19	32.1	19	29.6
Max	39	15	100	35	45.2	45.4	51.3
Obs.	5992	6752	15622	15,454	17,026	19,464	3,415

Table 20 Terminal Simulation Model Variables and Parameters

Parameters	Description
x = 1, …	Unloaders
y = 1, …	Conveyors
z = 1, …	Weighbridges
s	Same Product Unloading Overlap
m	Conveyor Availability Coefficient
μ	Inter-Arrival Time (IAT)*
θ	Unloading Duration*
ρ	Weighing-out Duration*
σ	Weighing-in *(constant)*
τ_1	Drive from weighbridge *(constant)*
τ_2	Drive to weighbridge *(constant)*

* indicates random generation through Monte Carlo technique

Table 21 Simulation Model Event Times

Event times for truck *i* of payload *k**	
a_i	Arrival at terminal
b_i	Unloading start
c_i	Unloading finish
d_i	Weighing start
e_i	Weighing finish
f_i	Depart from terminal
Event times for terminal equipment	
U_x	Unloader *x* available at
C_y	Conveyor *y* available at
W_z	Weighbridge *z* available at
Performance Measurements	
υ	Waiting time prior to unloading (≥0)
ω	Waiting time prior to weighing (≥0)

ϕ	Turnaround Time

* indicates random generation through Monte Carlo technique

Equations 1-5 calculate truck-related events:

$$a_i = a_{i-1} + \mu \quad (1)$$

$$b_i = a_i + \max\left((\sigma + \tau), A_{xi}, C_{yi}\right) \quad (2)$$

$$c_i = b_i + \theta_{xi} \quad (3)$$

$$d_i = \max\left((c_i + \tau), W_{zi}\right) \quad (4)$$

$$e_i = d_i + \rho_{zi} \quad (5)$$

*max function chooses the largest variable from within the brackets

Equations 6-8 calculate the waiting and turnaround time indicators at a truck level

$$\upsilon_i = b_i - (a_i + \sigma + \tau_1) \quad (6)$$

$$\omega_i = d_i - (c_i + \tau_2) \quad (7)$$

$$\phi_i = \sigma + \tau_1 + \upsilon_i + \theta_{xi} + \tau_2 + \omega_i + \rho_{zi} \quad (8)$$

Equations 9-11 update the terminal infrastructure availability:

$$U_x = b_i + s * \theta_{xi} \quad (9)$$

$$C_{yi} = b_i + m * \theta_{xi} \quad (10)$$

$$W_z = d + W_{zi} \quad (11)$$

Equations 12-14 calculate terminal throughput, and average waiting and truck turnaround time indicators:

$$Throughput = \sum_{i=1}^{i=n} k_i \quad (12)$$

$$T.Time = \frac{\sum_{i=1}^{i=n}(\sigma + \tau_1 + \upsilon_i + \theta_{xi} + \tau_2 + \omega_i + \rho_{zi})}{n} \quad (13)$$

$$W.Time = \frac{\sum_{i=1}^{i=n} b_i - (a_i + \sigma + \tau_1) + d_i - (c_i + \tau_2)}{n} \quad (14)$$

$$Rel.25 = \frac{\sum_{i=1}^{i=n} 1 \; if \; T.Time \leq 25, 0 \; otherwise}{n} \quad (15)$$

Appointment System Utilisation and User Behaviours Simulation

The weigh-bridge data was used to calculate the truck inter-arrival time (IAT), by subtracting the arrival time of consecutive trucks and to explore the trucks payload distributions. The weigh-bridge and unloading ramp geo-fence data were used as well to understand the duration of each of these processes. The two-stage model thus requires additional parameters and a stage for calculating the truck arrival time (a_i).

Table 22 Appointment System Utilisation and User Behaviours Model Parameters

Variables	Description
l	Appointment Window Start
Parameters	**Description**
A	Appointment Window Length
P*	Punctuality

* indicates random generation through Monte Carlo technique

Equations 15 and 16 illustrate the truck arrival time calculation when trucks arrive appointed at the terminal:

$$a_i = l_i + P^* \quad (16)$$

$$l_i = l_{i-1} + A \quad (17)$$

Appendix E. Scenarios ANOVA and Tukey Tests

Table 23 Simulation Scenarios ANOVA Test Results

ANOVA Results	Df	Sum Squares	Mean Squares	F-value	P-val
IAT 7	5	4.62E+09	9.24E+08	389,296	<0.001
Residuals	8,794,322	2.09E+10	2373		
IAT 7.25	5	1.14E+09	2.27E+08	269,743	<0.001
Residuals	8,484,533	7.15E+09	843		
IAT 7.5	5	4.36E+08	8.71E+07	188,481	<0.001
Residuals	8,191,905	3.79E+09	462		
IAT 7.75	5	2.20E+08	4.40E+07	146,096	<0.001
Residuals	7,921,854	2.39E+09	301		
IAT 8	5	1.33E+08	2.66E+07	118,440	<0.001
Residuals	7,667,915	1.72E+09	224		
IAT 8.5	5	6.17E+07	1.23E+07	86,102	<0.001
Residuals	7,206,467	1.03E+09	143		
IAT 9	5	3.64E+07	7.29E+06	69,134	<0.001
Residuals	6,794,902	7.16E+08	105		
IAT 10	5	1.98E+07	3.97E+06	56,869	<0.001
Residuals	6,097,783	4.25E+08	70		

Table 24 Simulation Scenarios Tukey Test Results

Scenario	IAT 7	IAT 7.25	IAT 7.5	IAT 7.75	IAT 8	IAT 8.5	IAT 9	IAT 10
HCT-NOINT	-39.25	-16.77	-8.18	-5.15	-3.30	-1.36	-0.46	0.25
IWB-NOINT	-0.957	-3.672	-2.20	-3.08	-3.34	-3.34	-3.21	-3.29
TAS-NOINT	-51.83	-28.74	-18.50	-14.20	-11.65	-8.35	-6.50	-4.59
CON-NOINT	-19.69	-7.984	-3.90	-2.69	-1.90	-1.07	-0.64	-0.35
RAM-NOINT	-56.27	-28.74	-17.10	-12.10	-9.10	-5.60	-3.76	-2.08
IWB-HCT	38.29	13.09	5.97	2.06	-0.04	-1.97	-2.75	-3.55
TAS-HCT	-12.58	-11.97	-10.4	-9.13	-8.35	-6.99	-6.03	-4.85
CON-HCT	19.55	8.78	4.27	2.45	1.39	0.29	-0.18	-0.61
RAM-HCT	-17.01	-11.97	-8.96	-6.95	-5.80	-4.24	-3.29	-2.34
TAS-IWB	-50.87	-25.07	-16.38	-11.2	-8.31	-5.01	-3.28	-1.30
CON-IWB	-18.73	-4.312	-1.70	0.39	1.44	2.27	2.57	2.93
RAM-IWB	-55.31	-25.07	-14.93	-9.02	-5.76	-2.26	-0.54	1.20
CON-TAS	32.13	20.76	14.68	11.59	9.75	7.28	5.85	4.24
RAM-TAS	-4.43	0.01	1.45	2.18	2.54	2.74	2.73	2.51
RAM-CON	-36.57	-20.75	-13.23	-9.41	-7.20	-4.53	-3.11	-1.72

* All differences significant at p<0.001 except RAM-TAS under IAT 7.25 and IWB-HCT under IAT 8

Appendix F. Appointment System Parameters and User Behaviours[13]

The average truck turnaround times for the scenarios analysed are presented in Table 25. The first line in the table, where an average of 6 unappointed trucks arrive at the terminal each hour, resembles the empirically observed situation at the terminal. The following 5 lines in each scenario truck illustrate the simulation results of respectively 20, 40, 60, 80 and 100% appointed arrivals. Each increment in the proportion of appointed arrivals can improve average turnaround times by approximately 5% in the low arrival frequency scenario, close to 10% for medium and high arrival frequency scenarios. Interestingly, in the case of high arrival frequency, the first increment in appointed arrivals has the largest impact in reducing turnaround times.

Table 25 Simulation Results for Punctuality

App. Arrivals	App/ Hour	High Punctuality		Med. Punctuality		Low Punctuality	
		Avg. TT	TT Sd.	Avg. TT	TT Sd.	Avg. TT	TT Sd.
0%	6 (Low)	21.0	9.5				
20%		20.1	8.2	20.2	8.3	20.4	8.4
40%		18.8	7.0	19.1	7.1	19.6	7.5
60%		17.8	6.1	18.3	6.4	19.2	7
80%		17.1	5.6	17.7	5.9	18.8	6.7
100%		16.5	5.1	17.4	5.7	18.5	6.4
0%	7 (Med.)	24.8	13.2				
20%		23.0	10.5	23.2	10.7	23.6	10.9
40%		20.8	8.5	21.3	8.7	22.1	9.3
60%		19.3	7.1	20.1	7.7	21.4	8.5
80%		18.4	6.5	19.3	7.0	20.7	7.9
100%		17.7	6.1	18.9	6.8	20.4	7.7
0%	8 (High)	40.9	28.5				
20%		28.9	14.9	29.6	15.3	30.1	15.3
40%		25.2	11.5	25.9	11.7	27.4	12.8
60%		23.4	10.3	24.2	10.5	26.0	11.6
80%		22.1	9.5	23.0	9.7	25.2	11.0
100%		21.1	8.9	22.6	9.5	24.5	10.4

The variability of turnaround times also decreases as the proportion of appointed arrivals increases. The variability of turnaround times, measured by the standard deviation, decreases in all three arrival frequency scenarios: For 6 trucks/hour, the decrease is approximately 40% between all unappointed and all appointed arrivals, close to 55% for 7 trucks/hour and

[13] This section is an extract from Neagoe, M., Hvolby H-H., Taskhiri, M. S., and Turner, P (2019d) Modelling the supply chain impact of a digital terminal appointment systems parameters and user behaviours. A discrete event simulation approach. Proceedings from the Australasian Conference on Information Systems. 2019

approximately 66% for 8 trucks per hour. A lower truck arrival punctuality can translate into a limited reduction in turnaround time variability as the appointed arrivals proportion increases.

Table 26 Simulation Results for Appointed and Unappointed Vehicles

App. Arrivals	**App/ Hour**	**High Punctuality**		**Med. Punctuality**		**Low Punctuality**	
		App. Avg. TT	**Unapp. Avg. TT**	**App. Avg. TT**	**Unapp. Avg. TT**	**App. Avg. TT**	**Unapp. Avg. TT**
0%		N/A	21.0				
20%		18.4	20.5	18.6	20.7	19.0	20.8
40%	6	17.6	19.7	17.9	19.8	18.5	20.4
60%	(Low)	17.0	18.9	17.6	19.4	18.5	20.2
80%		16.7	18.5	17.4	19.0	18.5	20.1
100%		16.5	N/A	17.4	N/A	18.5	N/A
0%		N/A	24.8				
20%		21.1	23.4	21.3	23.6	21.8	24.0
40%	7	19.5	21.7	19.9	22.1	20.8	23.0
60%	(Med)	18.5	20.5	19.3	21.3	20.5	22.6
80%		18.0	19.9	19	20.8	20.3	22.3
100%		17.7	N/A	18.9	N/A	20.4	N/A
0%		N/A	40.9				
20%		26.5	29.5	27.3	30.2	27.7	30.7
40%	8 (High)	23.7	26.2	24.4	26.8	25.9	28.5
60%		22.5	24.7	23.3	25.5	25.1	27.5
80%		21.7	23.6	22.6	24.5	24.8	27.1
100%		21.1	N/A	22.4	N/A	24.5	N/A

Both appointed and unappointed trucks can experience reductions in turnaround times at the terminal, with appointed trucks accruing more benefits. The average turnaround times of appointed and unappointed trucks in all scenarios are presented in Table 26. In virtually all the punctuality and appointed arrivals scenarios, appointed trucks have lower turnaround times. Lower arrival punctuality decreases the difference between turnaround times of appointed and unappointed trucks; however, the differences continue to be significant in all cases. On average, appointed trucks can perform between 8-10% better when compared to unappointed trucks. Nevertheless, unappointed trucks also benefit from the increased proportion of appointed arrivals. The next section discusses the implications of this research in the context of the broader investigation and the extant research literature.

Appendix G. Grounded Theory-Based Coding Core Categories

Congestion Factors

Table 27 Congestion Factors Core Category - Axial and Open Codes

Open Codes	Axial Code	Core Category
Exploration: centralised scheduling, clustered truck arrivals, collaborative transport planning, control over partners operations, creating own congestion, delivery quota, delivery slow-down, fleet cartage, independent operations management, lack of communication between transporters, multiple parties' bottlenecks, quota on operations, Stakeholders working together, terminal maintenance impacts, transport and production misalignment, truck arrival management **Stage 2: Stage 2: Design Workshops:** collaboration outside contract, coordination impact, intersecting flows consequences, lack of control, need for coordination, port central player, port governance requirements, production coordination, terminal central player, transporter coordination, truck arrival management	Limited coordination	Congestion Factors
Exploration: "inside vs outside", "the boat might not come back", competitive behaviour, competitors closure affecting deliveries, congestion challenges, congestion not seen in isolation, congestion shifting, core supply chain objectives, delivery slow-down, equipment relocation, fragmentation, frequent vessel arrivals, full supply chain, internal fragmentation, interruptions implications, just in time production, misaligned operations, miscommunication implication on congestion, mutual benefit, night-time staff availability, off-site queuing, operating hours misalignment, operational bottleneck, operational complexity, operational control, production and transport fragmentation, production changes affect balance, production distance to terminal, production fluctuation, production instability, production quality management, production restrictions, quality variation causes, reducing demand, resource quality affecting production, ripple effect, rostering challenges , seasonal influences, shipping schedules changes, staff availability, stock management, supply chain importance, terminal as intersection point, terminal available 24/7, their business impacting my business, throughput increase consequences, transport management **Stage 2: Design Workshops:** congestion is a by-product, driver preference, harvesting operations affecting congestion, port responsibility to community, production changes affecting congestion, production-transportation misalignment, transport and production relationship	Interdependence of operations	
Exploration: "burning money", communication misalignment, competitive behaviours of transporters, conflicting objectives, congestion "is what it is", congestion effects on terminal, congestion mitigation criticality, contractual delivery obligations, contractual incentives, cost implications for throughput targets, demurrage for truck waiting, diverging perspectives, drivers circumventing technology, financial incentives, impossibility of withholding transport, insufficient terminal capacity utilisation, it's more of an inconvenience, misaligned management	Misaligned Incentives	

decisions, no legal authority, optimal capacity, optimal truck flows, profit focus, profit vs value add, throughput increase, throughput standard maintained, vested interest **Stage 2: Design Workshops:** "not really our problem", contractual deliveries management, contractual delivery obligations, driver working hours, push contractor to change, return on investment uncertainty	
Exploration: "Bigger isn't always better", contractual nominal terms, meeting contractual performance threshold, terminal unloading procedure, turnaround time expectation, turnaround times, unloading staff performance **Stage 2: Design Workshops:** efficiency maximisation, throughput increase, turnaround time expectation	Performance Expectation
Exploration: biggest in the world, capacity expansion, contractor equipment , delivery cycle speed, eliminate single bin trucks, infrastructure repair delays, limited impact of additional infrastructure, limited unloading capacity, reduce production, surge capacity, terminal layout, terminal processing capacity, terminal storage capacity , terminal unloading capacity , weigh-bridge congestion, weigh-bridge enhancements **Stage 2: Design Workshops:** insufficient storage, operation alignment consequences	Infrastructure Limitations
Exploration: alternative delivery, alternative product competition, alternative product exports, contractual requirements for deliveries, dynamic production schedule, extended opening hours, geographical flexibility, just-in-time production, loading & unloading constraints, meeting demand, operational adjustment to production, production buffer, production restrictions, surplus equipment, surplus workload, unloading inflexibility **Stage 2: Design Workshops:** alternative delivery, port access	Supply Chain Inflexibility
Exploration: affecting other port users, breakdown-related congestion, contamination implications, contamination-related transport interruption, external maintenance works, fire ban days, holidays, holidays , interruptions implications, maintenance scheduling for minimal impact, maintenance works, operational interruptions, other terminal users , preventive maintenance, product contamination, production interruption, sub-standard production implications, throughput increase consequences, transport interruption, weather restrictions **Stage 2: Design Workshops:** other users' impact on operations	Operational Disruptions

Role of Information Systems

Table 28 Role of Information Systems Core Category - Axial and Open Codes

Open Codes	Axial Code	Core Category
Exploration: "open and honest discussions", advance notice of maintenance, breakdown duration foresight, breakdown information dissemination, breakdown information sharing, contamination investigation, cooperation and issue acceptance, data pooling, direct communication, disseminating operational information, get across perspective, informal communication, informal information sharing, inter-organisation communication, internal communication, maintenance information sharing, product handling quality, product quality criticality, product quality management, prompting communication, regular meetings, sharing laboratory measurements, sharing production schedules, shipping focus, shipping schedules information, staff requirements information, stakeholder meeting facilitation, terminal central player, transporter communication, trust, willingness to participate, **Stage 2: Design Workshops:** "open and honest discussions", communication alignment addressing issues, communication continuation, informal communication on production, information sharing amongst port users, stakeholder meeting facilitation, monthly planning meetings, re-initiating information sharing, stakeholder meeting challenges, standardised procedures	Information Sharing	Role of Information Systems
Stage 1: Exploration: asking the right questions, commercial-in-confidence, communication barriers, contractual obligations, contractually mandated information, forgotten to share update, information aggregation, information coming down the chain, information gathering, reluctance, information withholding, limited field of view, manual data gathering, shipping information withholding, shipping schedules and rosters , shipping schedules updates , stockpile management information, supply chain wide information, vested interest for sharing **Stage 2: Design Workshops:** access to quality information, commercial-in-confidence, demand information requirements, information inconsistency, information requirements, information sharing approval	Information Asymmetry	
Stage 1: Exploration: contamination feedback, continuous review of performance, feedback on performance, feedback on quality variation causes, identify cause and limit occurrences, insufficient feedback, necessary behaviours for improvement, no follow up, regular update expectation, requesting improvements, resource quality feedback, shipping rescheduling, stockpile grooming decisions , visibility for better coordination , what we do with this information **Stage 2: Design Workshops:** feedback provision, no follow up	Behavioural Expectations	
Stage 1: Exploration: autonomous trucks, information timeliness impact, operations visibility for understanding patterns, real-time data improving efficiency, real-time information usefulness, reliability implications on performance, stock information helping management	Performance Improvement	

Stage 2: Design Workshops: appointment system expected improvements, artefact inadequate functionality, IT artefact focus, IT implementation focus, task automation	
Stage 1: Exploration: "cards on the table" , data sharing enabling measurement, limited effect of visibility, operations visibility, organisational data collection limitations, performance indicator dashboard, planned deliveries visibility, production summary , real-time data capture, self-service portal, transparency on production, visibility of contractors' operations **Stage 2: Design Workshops:** lack of operational visibility, operations and transport visibility, technology for visibility	Visibility Enabler
Stage 1: Exploration: daily product samples, delivery and GPS data, delivery data reconciliation, delivery summary, driver performance data, excel based data management, fault identification, information technology use, maintenance documentation, maintenance information system, maintenance software implementation, maximum capacity monitoring, operations data capture, payment monitoring, performance measurement, performance reporting, production data interrogation, production information system, production plan monitoring, production quality, production summary, shipping schedule management, stock management, system driven advice, target monitoring, throughput data reconciliation, tire performance monitoring, truck geo-positioning monitoring, vessel loading information, weather data capture, weigh-bridge data collection	Monitoring Compliance and Operations
Stage 1: Exploration: "communication is key", breakdown communication, direct communication, email for communication, informal telephone communication, information dissemination, inter-organisational communication, interruption communication, phone for communication	Communication Enabler
Stage 1: Exploration: "snap decisions", advance decision making, advance information on deliveries, cause-and-effect modelling, data driven decisions, data-driven production planning, decision consequences, forecast sharing, forecasting inaccuracy, forecasting time-frame, increased data accuracy, lack of forecasting, maintenance scheduling forecasting, maximum economic capacity, operational decisions, operational decisions impact prediction, operational foresight, performance reporting, production scheduling, reaching maximum capacity, recognise patterns, rolling plan, scenario analysis, shipping schedules forecasts, short-notice forecast, traffic light system **Stage 2: Design Workshops:** manipulating schedules, performance reporting, production restrictions	Decision Support

Congestion impacts and consequences

Table 29 Congestion Impacts Core Category - Axial and Open Codes

Open Codes	Axial Code	Core Category
Stage 1: Exploration: additional working hours, early arrivals for economic viability, shipping costs, stockpile management costs, throughout-dependent rates, transport contractors most affected, transport profitability impairment **Stage 2: Design Workshops:** "death by 1,000 cuts", congestion cost consequences, cost of doing business, cost restructure, money spent on efficiency	Increased Costs	Congestion impacts and consequences
Stage 1: Exploration: common sense, frustration, get kicked down, lack of common sense, operational pressures, staff motivation **Stage 2: Design Workshops:** congestion frustration, driver frustration	Frustration	
Stage 1: Exploration: congestion limiting customer volume, insufficient shut-down time, maintenance budget, maintenance budget spend backlog, maintenance execution delays, maintenance lag, maintenance on old equipment, maintenance requirements, procurement process lag **Stage 2: Design Workshops:** port access leading to strategic decisions, unexpected delays	Uncertainty	
Stage 1: Exploration: customer business dependency, international recognition, unreliability implications, high volume, low margins **Stage 2: Design Workshops:** port impact on competitiveness	Competitiveness	
Stage 1: Exploration: bankruptcy risks, contractors' loss absorption , loss absorption possibility, maintenance lag risk, operations efficiency, revenue dependent on contractor performance **Stage 2: Design Workshops:** near-miss incidents	Resilience	
Stage 1: Exploration: chain of responsibility importance, fatigue management, compliance breaches, federal compliance, managing drivers' hours, relief drivers for fatigue management	Compliance Management	

Appendix H. Case B - Workshop Agenda

Table 30 Workshop Agenda Exemplar

Time	Workshop structure
10:00	Introduction: a) Participants introductions; b) Terminal operator introduction; c) Round-table discussion of supply chain challenges moderated by the research team;
11:00	Coffee-break
11:15	2. Supply chain and congestion findings presentation by the research team a) Challenges, recommendations and findings; b) Feedback on findings and recommendations;
11:45	3. Collective identification of approaches and technologies to address congestion guided by the research team
12:30	Working lunch

Appendix I. Workshop Worksheet Exemplars

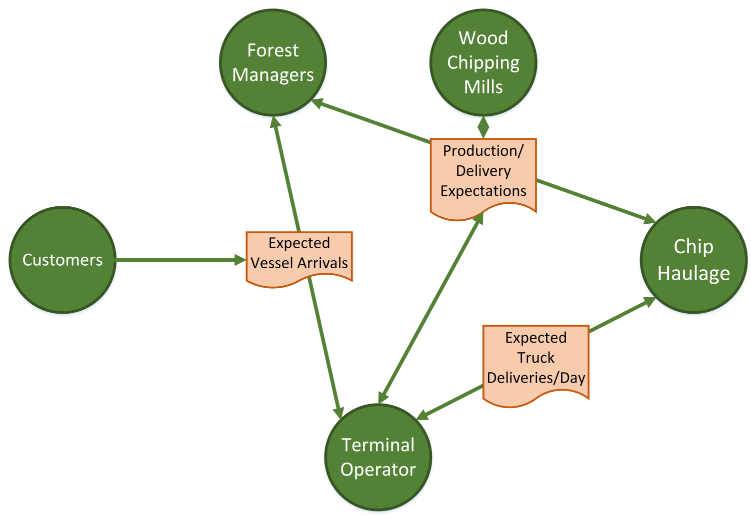
Case A Worksheet

Case A

Design Workshop
Worksheet

23rd August 2018

Information Sharing
Initial Ideas for Discussion



What information would you like to have?

Information Sharing
Initial Ideas for Discussion

New Information

- What Infromation?
- When? (Advance Notice)
- How? (Technology)
- With Whom?
- How Often?
- How to Deal with Unexpected Changes?

Expected Vessel Arrivals

- Vessel Arrival Interval
- Forecast 6 Months in Advance
- Email
- Terminal (BD Manager, Stockpile Supervisor) → weekly email to interested parties with known vessel arrivals intervals
- Every Month
- Update on Email ASAP

Expected Truck Deliveries/Day

- Number of Trucks in a 12/ 24 hour period. Expected Shift Start/Change/Finish. Planned number of deliveries
- Forecast 1 Week in Advance
- Email
- Terminal (BD Manager, Stockpile Supervisor) → weekly email to interested parties with known vessel arrivals intervals
- Daily/Weekly
- Update on Email ASAP

How should the information be shared?

Impact Evaluation
Initial Ideas for Discussion

1. Performance Indicators of Interest
2. Driver Experience
3. Uncertainty/Forecasting Changes
4. ________________________________
5. ________________________________

What factors could be used to track impact?

Impact Evaluation
Initial Ideas for Discussion

Performance Indicators

- Turnaround Time
- Vessel Demurrage Days
- Terminal Down Time
- Deliveries per Day

Driver Experience

- Perception of Facility Performance
- Perception of Fatigue

Uncertainty/Forecasting Changes

- Planned versus Actual Truck Deliveries

What indicators would be relevant?

Information systems and technologies

1. Existing information systems
2. Communication between organizations
3. TAS wants & needs
4. ______________________________
5. ______________________________

What technologies would be useful?

Cases B & C Worksheet

Case C

Design Workshop
Worksheet

29th November 2019

Designing a Way Forward

1. Information Sharing
2. Evaluation Criteria
3. Information Systems and Technologies
4. ……………………………………………………..
5. ……………………………………………………..

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Information Sharing
Initial Ideas for Discussion

What information?	When/How Often?	With Whom?	How (Technology)?	Dealing With Change?
Number and arrival times of trucks on site	Every Hour	Logistics managers Or Drivers	Excel on Email Or Text Message	Email Or Text Message

What information do you need to have?

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What information would you like to have?

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How should the information be shared?

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Impact Evaluation
Initial Ideas for Discussion

Performance Indicators

- Turnaround Times/Hour
- Trucks/Day
- Facility Shut-Down Times

Driver Experiences

- Perception of Facility Performance
- Fatigue Management (long shifts?)

What factors could be used to track impact?

What indicators would be relevant?

Information Systems and Technologies

Existing Information Systems

- Weigh-bridge
- Truck GPS
- …………………………………………………………

Communication Between Organizations

- Email
- Text Messages
- …………………………………………………………

New Information Systems

- Appointment System
- eDockets
- …………………………………………………………

What technologies would be useful?

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How would they work?

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