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Why are we still queuing? Exploring landside congestion factors in Australian bulk cargo port terminals

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ABSTRACT

This empirical research improves the understanding of landside congestion factors in bulk cargo port terminals. It presents a model for identifying factors and interactions contributing to congestion severity.

Ports play critical roles at the intersection of multiple independent supply chains and have an enormous potential to improve supply chains' competitiveness. However, this point of intersection for supply chains also creates significant coordination challenges best exemplified by the presence of landside congestion. Although landside congestion is an issue that plagues many ports and terminals, research on congestion remains limited, especially in bulk cargo port terminals. This lack of research may also partially explain the dominance of market-based mechanisms for managing congestion. Importantly, market-based approaches often fail or shift congestion to other parts of the supply chain because they are not aligned with the causal factors and their interactions that contribute to congestion.

This paper analyses three case studies. Each case centres on an Australian bulk cargo port terminal for forest products and its associated landside supply chain. The research findings identify social, technical and behavioral factors and their different types of interactions at the terminal and related supply chains and reveal how these factors contribute to the appearance and severity of landside congestion. Based on these findings, the paper presents a new definition of landside congestion and a model for identifying and understanding interactions among congestion factors. Improved knowledge of landside congestion can refine congestion management through contextually tailored solutions depending on the factors' presence and interactions.

1. Introduction

Ports are a critical element at the intersection of multiple independent supply chains and have enormous potential to add value to supply chains (Robinson 2002). However, this position at the intersection of supply chains creates coordination challenges exemplified by landside congestion. The consequences of landside congestion range from delays, lost time or sales, service uncertainty for transporters and logistics service providers (Meersman et al., 2012) Davies and Kieran 2015), increased supply chain costs (Loh and Thai 2015), uncertainty and ultimately decreased competitiveness. However, in a global context, supply chains compete (Christopher, Peck, and Towill 2006). Therefore, Increased costs and uncertainty in some supply chain areas can have broader competitiveness

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implications.

While landside congestion management has been extensively studied (Wibowo and Fransoo 2020; Yi et al. 2019; Schulte et al. 2017; Giuliano and O'Brien 2007; Morais and Lord 2006), there are significant knowledge gaps in terms of congestion factors. The lack of understanding of landside congestion factors means that congestion management approaches may treat symptoms rather than causes. Congestion management approaches can thus fail or be less effective than anticipated because they were not aligned with the causal factors (Motono et al. 2016). Furthermore, landside congestion has been extensively studied in container terminals (Covic 2017; Li et al. 2018). However, landside congestion in bulk cargo terminals has been largely overlooked. A better understanding of landside congestion factors, particularly in bulk cargo port terminals, can help align management approaches with factors and thus increase their effectiveness.

Forest products are an important Australian commodity export (Ports Australia 2019). The export supply chains of forestry products are typically unidirectional, highly fragmented, involving multiple participants in each stage of the chain and spread over a large geographical distance. Because forest products are considered a commodity, the supply chain participants are generally extremely cost-conscious as costs affect the supply chain's competitiveness with supply chains based in lower-cost areas of the world. Despite the large geographical distances, and its historical role in forest products supply chains (Brett 2018), rail is not used for transport in the three cases studied. However, high-capacity trucks are typically used to fulfill the logistics task (Cameron 2005; NHVR 2018).

This empirical research aims to improve the understanding of landside congestion factors in bulk cargo port terminals via three case studies supported by semi-structured interviews and site visits. The three case studies are each set in Australian bulk cargo port terminals for forest products. One case is set in Burnie, Tasmania, and the other two are set in Portland, Victoria. The resulting data were analysed using coding principles drawing on grounded theory. The lack of research or theoretical frameworks of landside congestion factors made this investigation suitable for qualitative data collection and analysis techniques favouring inquiry depth over breadth. Grounded theory-based coding principles support exploring qualitative data and the emergence of connections between categories in terms of "*conditions, context action/interactional strategies and consequences*" (Strauss and Corbin 1990).

The main contributions of this paper to the body of knowledge are 1) a landside congestion definition and 2) a model of congestion factors that can be used by researchers and practitioners alike as a sensitizing device for understanding congestion and honing congestion management approaches.

The paper is structured as follows: The research literature on landside congestion and management is discussed, followed by the multiple case study approach and the data analysis results. Hereafter, the congestion factors model and the landside congestion definition are developed and discussed in relation to the existing literature and finally, the conclusions of this research are presented.

2. Literature Review

Port congestion is a common issue in freight logistics and supply chains. Generally, congestion is 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, generating costs for third parties (Meersman et al., 2012). The two main types of congestion are recurring and non-recurring. Recurring congestion tends to occur regularly in specific 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 congestion is the build-up of queues (Meersman et al., 2012). However, the consequences of congestion are further reaching and more complex than just time delays.

Landside 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, increasing costs, fuel consumption, emissions (Taudal and Sampson 2020), and decreasing assetproductivity. These impacts ultimately reduce the transport operators' earnings (Huynh, Smith, and Harder 2016). Congestion can be perceived as an inconvenience and source of frustration for truck drivers and can also increase the risk of accidents (Meersman et al., 2012). In ports, the most visible consequences of congestion are the increase in truck turnaround or service times (Davies and Kieran, 2015). However, congestion also generates significant uncertainty. Uncertainty contributes to increased inventory, warehousing, transportation costs (Loh and Thai 2015), and decreased overall transport performance (Meersman et al., 2012). Given the broad-reaching consequences of congestion, it is critical to understand the factors leading to its appearance before attempting to mitigate congestion.

Several congestion factors are mentioned in the research literature but are rarely explored in detail. At a high level of abstraction, Kockelman (2004) presents three main factors for the appearance of traffic congestion, mainly: inadequate supply of infrastructure, imperfect information flows or flawed policies and regulation. In ports, the capacity mismatch between the port and logistics tasks, labor and equipment shortages and weather events are frequently mentioned (Meersman et al., 2012); Nze and Onyemechi 2018). Gumuskaya et al. (2020) highlight the impact of coordination and conflicting incentives in logistics operations and particularly concerning the appearance of congestion. In one of the few case studies investigating congestion factors, Motono et al. (2016) identified "*improper documentation*" as a congestion factor addressed by the terminal operator using a technology platform. The researchers highlighted that previous congestion mitigation methods had failed, likely because they were misaligned with the factors causing congestion (Motono et al. 2016).

Frequent or peaking truck arrivals are also indirectly considered a congestion factor. An extensive body of knowledge focuses on the potential and actual impact of terminal appointment systems (TAS) on landside congestion in container port terminals (Wibowo and

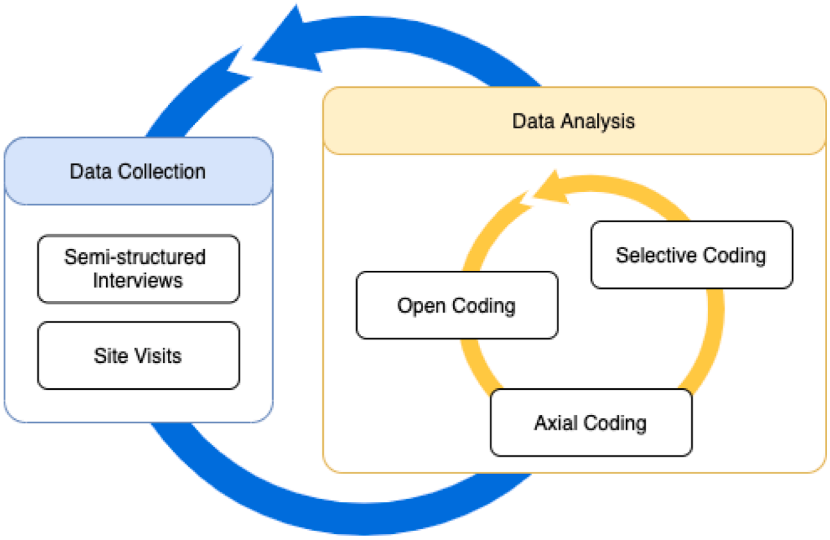

Fig. 1. Research Design Diagram

Fransoo 2020; Yi et al. 2019; Schulte et al. 2017; Huynh, Smith, and Harder 2016; Covic 2017). The fundamental ,often implied, position assumed by researchers is that a more even distribution of truck arrivals in port terminals will reduce landside congestion. This asssumption has been supported by research using analytical methods such as queuing theory and linear programming. Chen, Zhou, and List (2011) modeled truck arrivals using queuing theory and found a turnaround time reduction by as much as 60 min using a terminal appointment system, from 100 to 40 min. Chen, Govindan, and Yang (2013) modeling revealed a decrease in truck waiting times by as much as 93 min, from 103 to 13 min on average, through appointment systems. Modal shift to rail or short-sea shipping has also been discussed to mitigate landside congestion (Konstantinus 2021; Aregall, Bergqvist, and Monios 2018). To date, most research into congestion management centres around container terminals and limited research has investigated congestion management approaches in bulk cargo terminals (Neagoe et al., 2021).

Although there are some differences between container and bulk terminals, the insights obtained studying containerized operations can be, to some extent, transferrable to bulk operations. The significant differences between container and bulk terminals are cargo flows direction and terminal operations complexity. Container terminals are bidirectional, while bulk cargo terminals usually cater to export or import cargo (Unsal and Oguz 2019). Consequently, container terminal operations are typically more complex. The loading and unloading of trucks and vessels are performed by mobile equipment – rubber tyre gantry cranes - and cargo is transferred using yard trucks or automated guided vehicles. Conversely, loading and unloading equipment in bulk cargo terminals is generally fixed, and cargo is transferred using fixed conveyor belt systems. Nonetheless, both bulk and container terminals present similarities in their operations (Bugaric et al. 2012) and particularly in relation to landside logistics.

Although much is known about landside congestion and its management, particularly in container terminals, several notable gaps remain in the literature. First, the definition of congestion is broad and has limited practical usefulness, particularly in port settings. The congestion factors considered so far occur at different abstraction levels and provide limited insights into addressing them. Factors such as "*insufficient infrastructure*", for example, are relatively broad and uninformative. Which piece of infrastructure? Is the limited access to infrastructure a problem? Is the infrastructure insufficient during the entire day or operating time of the facility? How often is the infrastructure closed down due to severe weather or accidents? Second, congestion appears to be considered an implacable issue. Recurrent congestion generally occurs at known locations and times, resulting from an imbalance between supply and demand. However, few studies have investigated why this imbalance occurs in the first place. Third, researchers have highlighted the potential impact of smoothing truck arrivals at terminals, yet few studies have investigated why truck arrivals peakduring any given day. Although analytical approaches have shown possible improvements in truck turnaround times, empirical studies of congestion mitigation approaches aimed at smoothing truck arrivals have yielded conflicting outcomes (Giuliano and O'Brien 2007; Davies and Kieran 2015). Finally, landside congestion has been explored almost exclusively in container terminals to the detriment of bulk cargo terminals. Bulk cargo terminals generally handle low-value, high-volume commodities. Therefore, logistics inefficiencies caused by congestion are likely to impact the overall economic viability of such supply chains significantly. Given these gaps, this investigation aims to improve the understanding of landside congestion factors in bulk cargo marine terminals.

The following section describes the multiple case study approach adopted to explore congestion factors.

3. Methodology

This work's exploratory nature means that it lends itself well to a qualitative inquiry. The methodology adopted in this empirical research is a multiple case study approach. Data were collected by the researchers using semi-structured interviews and site visits and were analysed using a grounded theory-based coding process.

Table 1
Data collection stages and timeframe

Data Collection	Case Study A	Case Study B	Case Study C
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)
Interview Respondents [a]	Alex (TO)	Arthur (TO/WP)	Anthony (TO/FC)
	Bobby (TR)	Beatrice (TO/WP)	Brian (TO/FC)
	Charles (FC)	Carter (TR)	Christine (WP/TR)
	Danny (FC)	Damien (TR)	David (WP/TR)
	Elliott (FC)		Eric (WP/TR)
	Frank (TO)		Fred (WP/TR)
	Garry (WP)		Gabriel (WP/TR)
			Henry (WP/TR)

TO = port Terminal Operator; FC = Forestry Company; WP = Wood chip Producer;
TR = Transport Company;
[a] The respondent's names have been changed to protect their anonymity

Case study research is primarily concerned with understanding a contemporary phenomenon (Yin 2003). It is especially useful when there is limited conceptual development of the phenomenon of interest. The existing perspectives have little empirical substantiation casting doubt on the adequacy to explain the phenomenon (Eisenhardt 1989). Multiple cases can partially overcome the shortcomings of a single case concerning their generalisability, the causal relations identified (Cavaye 1996), and the possibility that findings result from case idiosyncrasies (Miles and Huberman 1994).

The research design consisted of semi-structured interviews and site visits as data collection methods and grounded theory-based coding principles for data analysis. Fig. 1 helps visualize the research design and the interaction between data collection and analysis. Semi-structured interviews were the primary data collection method used in this research. Interviews can capture the diverse aspects of the social world from those involved without the reliance on numbers (Horrocks and King 2010). The qualitative data collected during all research stages were analysed using a grounded theory-based coding approach (Strauss and Corbin 1990). The grounded theory-based tools and techniques used to analyze qualitative data included open, axial and selective coding, constant comparison, and analytical memos and conceptual diagrams.

Three case studies were conducted, focusing on a bulk cargo port terminal for forest products and the associated landside supply chains. Data were collected between August 2017 and August 2019 and included 25 semi-structured interviews and 13 site visits. Table 1 summarises the research timeline and the data collection activities. This investigation has been approved by the Human Ethics Research Committee (Tasmania) under ref: H0016718.

The semi-structured interviews were conducted over the phone or face-to-face at agreed times. The interviews' length ranged from 30 to 90 min. Eleven 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 into five categories: background, responsibilities, information and technology use, congestion challenges and consequences and management approaches (see Appendix). The interviews were conducted with terminal operator staff and participants in the supply chains' landside – transporters, producers, forest owners or managers. In several cases, one organization was responsible for managing several parts of the supply chain. For example, transport companies and terminal operators also processed wood chips. Similarly, some forestry companies operated their own terminals. It was expected that this overlap in roles would highlight additional differences in perspectives and perceptions on congestion.

The data emerging from the three cases were pooled during the grounded theory-based coding. The first author of the paper partially transcribed the interviews to aid in the coding process. Open coding was first applied to the transcripts and notes. The open coding process resulted in 148 codes. Axial coding was used on the open codes to generate links between the different properties and dimensions of the data and form developed categories. This process yielded seven axial codes. Selective coding was then employed to refine and integrate the resulting categories from the axial coding process. The codes emerging from the analytical process are presented in the Appendix (Table 2). The researchers followed a constant comparison process, iterating between the data collection, data and the emerging categories from the analysis until a "*theoretical saturation*" was reached (Eisenhardt 1989; Walsham 2006). The researchers used analytical memos and conceptual diagrams to help develop theory, as immersion in the data facilitates the emergence of thoughts, relationships or ideas.

4. Case Studies Description

The three case studies each centred on a bulk cargo port terminal for forest products and the associated landside supply chains. One case was located in Burnie, Tasmania and two cases were located in Portland, Victoria. Although the supply chains in the three cases all handle the same product, wood chips, each case displays some peculiarities in their supply chain setup, as shown in Fig. 2. The red rectangle in each case highlights the scope of the case study.

The supply chain in each case starts with the harvesting process, where standing trees are felled. Forestry companies decide which coupes should be harvested. Contractors are employed to manage the harvesting process and generally operate independently of one another. Contractors generally provide equipment for harvesting, chipping and transporting logs and wood chips. In Case A, the felled

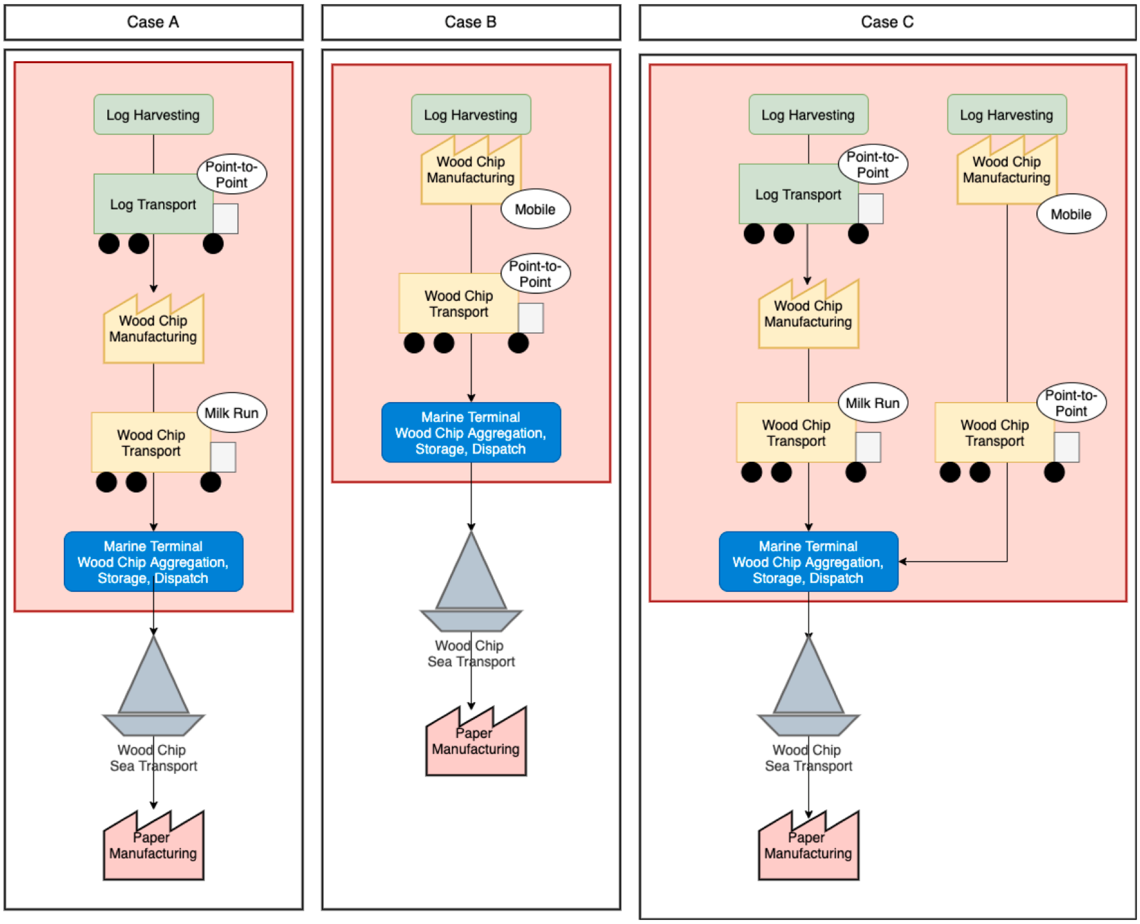

Fig. 2. Case studies' supply chains

trees are cut into standard-size logs. The logs are then transported to a wood chip processing facility. In Case B, the trees are processed into wood chips on-site using mobile chippers. The mobile chippers spray the wood chips directly into truck trailers. The harvesting process in Case C is a combination of Cases A and B. The wood chips are transported by large dedicated trucks that run between the processing facility or the mobile chipping sites and the port terminals. Each wood chip truck can load between 27 and 45 tonnes in Case A and between 50 and 60 tonnes in Cases B and C.

The port terminal in each case acts as an aggregation, storage and ship loading facility. A ship can be filled with the equivalent of 1,000 to 2,000 truckloads of wood chips. The port terminals handle between 1.5 and 2 million tonnes of wood chips each year. Wood chips from several harvesting coupes and several contractors must be aggregated over several weeks to fill a ship. In Case B, the port terminal also has a re-chipper facility where wood chips outside production specifications can be re-cut. Wood chip vessels generally managed or operated by large international pulp and paper manufacturers.

The truck unloading process at the terminals in the three cases is similar. Trucks are first weighed when they arrive on the terminal premise. The trucks then drive to a staging area on the wharf for unloading. Trucks are unloaded using hydraulic ramps that lift the trucks, forcing the trailers' contents to slide into a bin. The bin contents are carried on a series of conveyors to one or several stockpiles. The terminals in Cases A and C had two unloading ramps, while three ramps were present in Case B. Once trucks are emptied, the trucks are lowered and are weighed again. The difference between the first and second weight readings determines the net weight of the wood chips delivered. The time difference between the first and the second weigh-bridge reading determines the truck turnaround time, the key performance measure used in all cases to evaluate landside congestion severity. The minimum achievable turnaround time without queuing and operational issues are between 11 min in Case A and 15 min in Case B and C.

In all three cases, the port terminal operator, forestry and transport companies' staff raised issues regarding landside congestion. The congestion issues raised by staff in all cases were similar – long waiting times, extra costs, fatigue – although the average truck turnaround times were markedly different. The average truck turnaround time in Case A was 23 min; 35 min in Case B and 57 min Case C. These marked differences in turnaround time measures contrasted the similarities of participants' perspectives on congestion. This led the researchers to explore congestion in the three cases in more detail.

The following section describes the grounded theory-based coding results regarding the congestion factors identified across the three cases and their interrelationships.

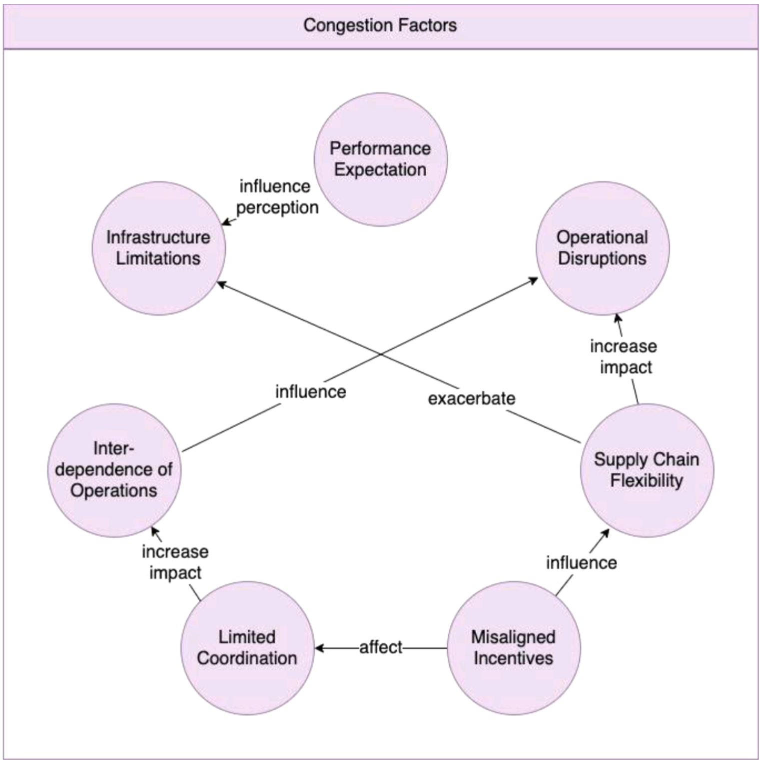

Fig. 3. Port congestion factors axial codes

5. Results

The site visits and observations helped researchers better understand the supply chain setup and its behaviours. Road transporters responded to the challenge of congestion by scheduling their drivers' shifts in 15 min blocks to space departures from depots. However, subsequently, coordination amongst drivers belonging to the same organization was limited and often ad-hoc. The wood chip mill visits helped the researchers understand the dependence between wood chip production and transportation and how this subsequently impacts port deliveries. Finally, the researchers observed irregular truck arrivals at the port terminals. Trucks would not arrive during lengthy periods. Afterwards, trucks arrived in close sequence, sometimes from the same site.

The grounded theory-based coding process led to the emergence of seven axial categories of port congestion factors: infrastructure limitation, the interdependence of operations, operational disruptions, limited coordination, incentive misalignment, supply chain flexibility, performance expectations. Fig. 3 illustrates the axial categories identified and their relationships emerging within the congestion factors core category. These are individually discussed and supported by interview data.

5.1. Performance Expectations

Several Case A and C participants commented on the terminal and average truck turnaround times' performance expectations. These performance expectations, in both cases, appeared driven by contractual terms. Charles' account illustrates how performance expectations were constructed in their organization's case.

Charles (Forestry Company/Case A): "*When we started,* [the transport operator] *did the stopwatch measurement of the tipping ramp of the port and submitted his tender. He had based his cost around a nominal turnaround time of 17* min*, that's where that 17* min *came from.*"

It is interesting to observe that the transport operator's stopwatch measurement was factored in as an average in the costings. However, it was unclear whether there were allowances made for the average variation or whether the average was considered equivalent to the maximum.

Performance expectations influenced the perception of infrastructure limitations. Truck turnaround times were also perceived to be affected by throughput levels compared to the capacity of the terminal's infrastructure. Brian's account highlights the 45 min threshold in terms of truck turnaround times:

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

The 45 min appeared to be the standard by which the facility's performance was compared, although it was unclear whether it represented the average or the maximum threshold. 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 min, while in Case C, the expectation was for a 45 min truck turnaround time.

5.2. Infrastructure Limitations

Infrastructure limitations, particularly relating to the terminal, were considered as one of the primary congestion factors 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 across all three cases. His account raises two issues relating to the terminal infrastructure: insufficient unloading infrastructure and 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 weighbridge 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 contributed to congestion. In Cases A and C, several terminal operator staff also recognized several infrastructure limitations. However, within the same organization, there were also cases of disagreement regarding the terminal infrastructure limitations.

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

It is important to note that the data collection in Case C took place while one of the three unloading ramps was not operational. Many respondents suggested that the breakdown had had a negative effect on their truck turnaround times and therefore contributed to the congestion.

5.3. Interdependence of Operations

Most participants across the three cases recognized the interdependence between operations in the supply chain. Interdependence was primarily recognized within the context of the individual supply chains in which organisations operated. Garry's story illustrates this:

Garry (Wood Chip Producer/Case A): "[Interviewer: If the vessel arrival time changes, let us say it goes out ten days, how does that impact your plan?] *Well, it impacts the deliveries and impacts the drivers. But that is not really ideal for our business because then we have to play onto the next product.* […] *it is critical that our shipping team deliver on what they say the vessels are coming and stick within the laycan*[1] *which is about ten days. It is critical to our business.*"

In an individual supply chain, changes in the shipping schedules can affect the transportation schedules and the truck arrival frequency at the terminal. The limited storage capacity at the terminal also plays a role in the impact of operational interdependence. However, it is imperative to note here that this interdependence was primarily recognized in the context of the participant's organization and supply chain but not necessarily in the context of other port users.

Site visits in Case C also revealed that trucks' availability influenced in-field wood chip production. During a site visit, the woodchip operator could not work because the trucks had not arrived in the forest coupe. Subsequently, several trucks arrived in close sequence. 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.

The level of supply chain coordination influenced the interdependence of operations. The terminals in each of the cases served as intersection points for multiple supply chains or 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* [Company X] *are going to campaign*[2] *a product after their next vessel so that is ultimately gonna keep* [Company Y's] *trucks out. It is not gonna affect our business because even though* [Company X] *have an increase in product,* [Company Y] *will see in their daily deliveries drop, but the facility will probably see an increase in tonnage.*"

One forestry company's decisions to temporarily increase production and, consequently, the number of trucks arriving at the terminal daily was expected to impact another's operations. These independent decisions taken by an individual company affected operational clashes with other terminal users and subsequently on the level of congestion experienced at the terminal.

5.4. Limited Coordination

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

[1] Laycan is an abbreviation for the "laydays and cancelling clause in a ship chartering contract. This clause establishes the earliest and latest dates from which a vessel can start its charter contract.

[2] Campaigning is used interchangeably with transportation

Individual organizations encountered challenges coordinating their internal operations and end up causing their own issues, as Garry's account illustrates:

Garry (Wood Chip Producer & Transporter/Case A): "*If I gotta campaign and put 7 or 8* [trucks] *on the run, it is not viable. Because sometimes you find that you are creating your own waiting times* […] *So, I find that 5–6 trucks are running here, I can't do anymore, because if I do, I am creating my own issues.*"

The short transport route between the wood chip processing site and the terminal in Case A 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 than others about internal coordination issues.

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

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

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

Notably, Alex's account also illustrates the limited coordination across the supply chain and how *supply chain coordination* was affected by *misaligned incentives*. Throughout the discussions with stakeholders, the times of day in which trucks would arrive were relatively well known across the three cases. However, coordination efforts along the supply chain were rare. This situation was facilitated by the misalignment of incentives 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] *need to start communicating between themselves"*.

However, respondents from other organizations 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 participants across the three cases much more frequently discussed. In Case A, two competing forestry companies independently scheduled their vessels, leading to landside operational clashes. This issue was frequently discussed because it led to demurrage payments for vessel waiting time. Nonetheless, although these events would occur with relative frequency, there was limited evidence of coordination between organizations or along the supply chain.

5.5. Misaligned Incentives

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 maximize overall profitability (Simatupang and Sridharan 2002).

The forestry companies, in all cases, scheduled vessel arrivals independently; 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 behavior led to vessel waiting times, which incurred costs for forestry companies and truck congestion since trucks are required to deliver continuously to ensure product availability. Alex summarises this competitive behavior:

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

Misaligned incentives influenced *supply chain flexibility*. Similarly, on the landside side, to fulfill 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] *would talk openly, he would tell me he is short 10,000 tons, and he needs to get them there, and I would equally say I am full with wood chips and I need to get them to the port."*

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

5.6. Supply Chain Flexibility

The supply chain flexibility level 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 Producer & Terminal Operator/Case B): "*if we have too much log here, we can move some of that resource to* [another terminal] *to relieve some congestion here. We do not have the same luxury with* [this other] *supply because we have a supply agreement for* [X] *million tons. It is imperative we try to meet that almost at the cost of our own wood supply.*"

On the timber production side, most chipping and transport operators in Cases B and C revealed that the changes in production site distance from the terminal could affect the congestion. Higher distances between production sites and the terminal would allow the trucking fleet to disperse and arrive at different intervals. In comparison, smaller distances would often lead to clustered truck arrivals.

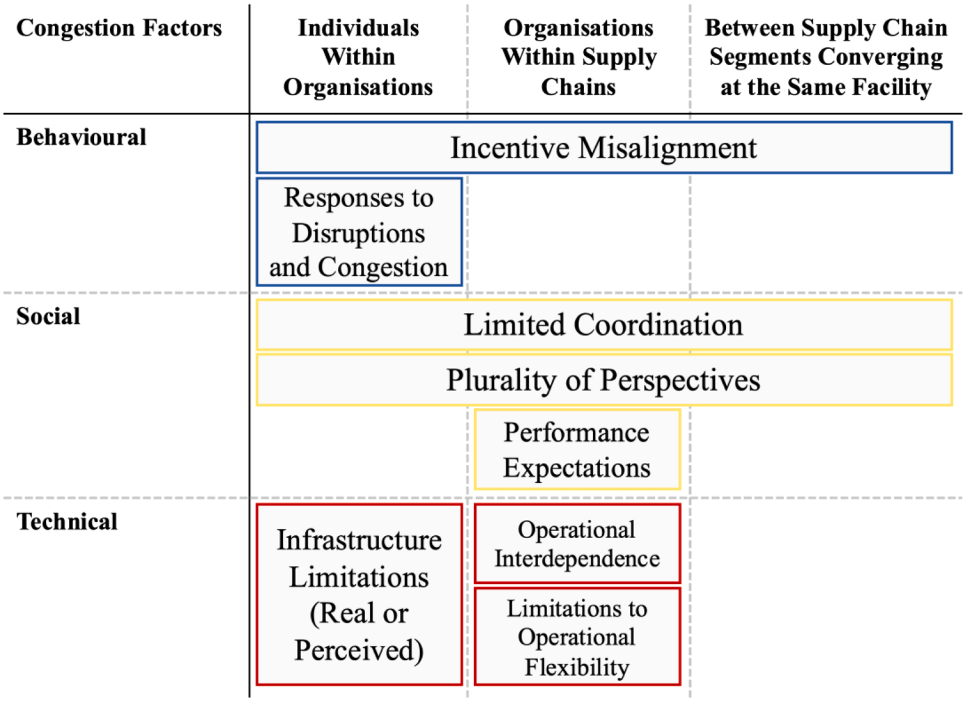

Fig. 4. Congestion factors model

Some operators were taking measures, where possible, to send trucks to the furthest production sites to limit waiting times at the terminal and potentially relieve congestion.

5.7. Operational Disruptions

Operational disruptions were also perceived as a congestion factor by many 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. As Bobby's story highlights, adverse weather would cause delivery suspensions at the terminal in Case A. 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 is easterly wind*[3]*, and they stop us tipping, there is a list that* [the terminal operator] *notify. So, they will notify me. So, I will get out of bed and send a group text message to all the drivers: '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.* […] *When the port opens, we can tip them off and then go back to the mill.*"

The level of supply chain flexibility influenced the impact of operational disruptions. Bobby's account also highlights that trucks can be sent out to different forest coups when multiple options are available, especially those located furthest away. Conversely, the limited flexibility of trucks in terms of unloading mechanisms can facilitate the appearance of congestion. Discussions with other participants revealed that some of the transporters would queue up their trucks at the terminal to be the first to unload if it was likely the terminal will resume unloading within a reasonable amount of time after a weather-related disruption.

The interdependence of operations influenced operational disruptions. Thus, the behaviours of other parties in the supply chain affected the appearance of operational disruptions. In Case C, the leading causes of operational disruptions were product contamination or sub-standard quality. Product contamination occurred when materials other than wood chips are delivered to the terminal. Any materials that may be unloaded from trucks have to be removed before they reach 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 was 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.

Notably, sub-standard product quality would also cause operational disruptions. This occurred primarily in Case C. 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 as this is the most important. Because if the chip comes in and it's*

[3] Easterly winds prevents truck unloading in this case because the fine dust particles agitated through the unloading process are carried away by the wind in the adjacent city. Fine dust particles can pose serious health risks

in spec the system runs smoothly. If you get a load of oversized chips, 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 penalized because he has to wait until that load is processed."

Sub-standard deliveries would likely have a cumulative effect on trucks already waiting at the terminal. A series of sub-standard deliveries would cause significant operational disruptions at the terminal.

The following section presents the results interpretation and the emerging model of congestion factors and congestion definition.

6. Interpretation

The interpretation process structured the results of this research in a systematic way. The researchers thus sought to identify dimensions across the congestion factors identified to structure the results. This led to the production of the congestion factors model presented in *Fig. 4*. The model categorizes factors into behavioural, social and technical and according to the level of analysis.

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) and individuals or organisations' **interactions with these assets**. The lines between the factors are purposely dotted to illustrate potential interactions between factors. These interactions were identified through data analysis (Fig. 3). No attempt has been made to prioritize these factors as isolating and quantifying the impact of individual factors was extremely challenging.

Congestion factors also interact across different analysis levels, from *individuals within organizations, organizations within supply chains* and *organizations between supply chains* converging at the same facility. Individuals in organizations and organizations within supply chains are generally directly or indirectly bound to one-another through contracts. In this research, information flows between companies tended to follow companies' contractual links. However, just because material flows of organizations intersect does not necessarily imply that the same organizations share information on these flows. For example, it is uncommon that haulage or transport contractors have contracts amongst themselves. Congestion often occurred due to the lack of information flows between organizations operating in different supply chains but converging at the same facility.

Performance expectations influenced the participants' perception of congestion. Although truck turnaround times were markedly different in the three cases, the participants' descriptions of congestion were strikingly similar. However, in all cases, contracts between participants specified an expected turnaround time for trucks. This expected performance anchored participants in a figure used to compare daily performance. This factor was particularly relevant because it suggested that landside congestion was socially and contextually defined rather than objectively constructed.

Infrastructure limitations were also one of the most discussed congestion factors. However, infrastructure limitations seemed more of a symptom rather than a congestion factor. In all cases, the terminals could process the daily volume of trucks, albeit some trucks would be discharged with some delays. While the terminals' capacity was sufficient to process the total volume of trucks, it was insufficient to cope with temporary peaks in truck arrivals. It was therefore considered likely that other factors such as limited coordination, operational interdependence or misaligned incentives led to played a more important role in the formation of congestion.

The *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). In contrast, 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 recognized 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 *limited coordination* also played a role in congestion, as evidenced in the three cases. The most evident manifestations of this issue were peaking truck arrivals. However, the limited coordination of logistics and production operations contributed to fluctuating truck arrivals, leading to queuing and increased truck turnaround times.

Incentives within organizations, supply chains and between supply chain segments were often *misaligned*. The misalignment of incentives was partially related to fragmentation between and within organizations. Organizational incentives, mainly financial, were often conflicting, particularly in competing organizations. Consequently, short-term organizational goals, such as fulfilling orders or improving profitability, were likely to take precedence over collaboration to address supply chain issues.

Interestingly, the terminal operator had few direct incentives to mitigate congestion. The terminal operator generally did not have a contractual relationship with the transporter companies. The transporters were generally subcontracted by chipping or harvesting companies, themselves subcontracted by forestry companies. As a result, the terminal operator rarely experienced significant consequences of congestion apart from the truck operators' frustration. As long as the terminal operator would reach volume or revenue targets, congestion was not perceived as a significant issue.

The *plurality of perspectives* amongst stakeholders was also a congestion factor. This emerged from comparing the differences between individual views on congestion. The researchers realized that all respondents experienced and perceived aspects of congestion. However, these perspectives were rarely shared between individuals operating in the same supply chain. Congestion was generally considered a nuisance outside the participant or organization's control. This perspective meant that congestion was an issue for which someone could be blamed, generally the terminal operator.

Furthermore, organizations rarely recognized 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. The absence of a shared perspective amongst participants meant that they could not recognize their roles in congestion and that no congestion mitigation approach was likely to gain traction.

The 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 some 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 *operational disruptions* contributed to congestion. Following operational disruptions caused by weather, low-quality cargo or breakdowns, loaded trucks waiting at their depots would often swarm the re-opened terminal. 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. When trucks queued before the facility's opening time, they 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 organizations to ensure a first daily delivery. Thus, the disruption itself rarely led to congestion. Rather, the response of individuals and organisations to disruptions or the threat of disruptions led oftentimes to the formation of congestion.

The findings and model presented in this research also helped formulate a definition of landside congestion as: "*An emergent symptom of intersecting supply chains, characterized by higher-than-expected delays, generally manifesting at marine terminals, caused by a plurality of behavioral, social and technical factors and their interactions and a multitude of stakeholders' perspectives and associated individual response behaviors*".

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[4]. 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. The terminal operator's perceived responsibility for the broader community likely stemmed from the operator's public ownership structure. The responsibility for the broader community may have catalysed the involvement of the terminal operator in congestion mitigation attempts.

The next section discusses the findings in relation to the extant literature.

7. Discussion

This research contributes to the literature by highlighting that a holistic approach, integrating the terminal and landside elements of the chain, can reveal critical aspects of congestion. This research identifies a series of social, technical and behavioral landside congestion factors: performance expectations, terminal infrastructure, limited coordination of operations, interdependence with other operations, misaligned incentives, responses to operational disruptions and the 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.

This congestion definition developed in this research provides additional clarity, compared to existing definitions (such as Kockelman 2004), on how congestion emerges and the factors contributing to its appearance. This definition can expand researchers' and practitioners' perspectives on congestion-related issues and help focus more targeted congestion mitigation efforts.

Although recognized as a congestion factor in the extant literature (Meersman et al., 2012; Kockelman 2004), the inadequate terminal infrastructure is only a perceived congestion factor in this research. Indeed, the inadequate terminal infrastructure is a symptom of other congestion factors such as limited coordination, misaligned incentives rather than a factor in itself. Operational disruptions such as weather or accidents, also played a role in generating congestion (Meersman et al., 2012). However, in this research, individuals and organizations' behavioral 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.

This research provides evidence linking limited coordination and misaligned incentives for the appearance of congestion. These relationships have also been previously identified in the literature (Gumuskaya et al. 2020). This research complements the existing body of knowledge by highlighting the impact of coordination, incentives, and other factors at different analysis levels.

The next section presents the conclusion of this research.

8. Conclusion

This research explored the factors and interactions that contribute to the appearance of congestion at bulk cargo port terminals. Three case studies centred on three bulk cargo port terminals for forest products and their associated supply chains were conducted.

The data analysis process led to the identification of the following congestion factors: infrastructure limitation, the interdependence of operations, operational disruptions, limited coordination, incentive misalignment, supply chain flexibility, performance expectations. These factors were fundamental to the development of the congestion factors model. The model distinguishes between behavioural, social and technical congestion factors as well as factors mainly occurring between individuals in the same organization,

[4] A government business enterprise is a Commonwealth entity or Commonwealth company

factors occurring between organizations in the same supply chains and factors emerging from the interaction between supply chains intersecting at the port terminal. The findings of this research can be used to sensitize academics and practitioners alike to potential congestion factors present in other situations and consequently guide congestion management efforts towards the most effective approaches to address the most poignant congestion factors.

A key limitation often discussed in the context of case study approaches is the lack of statistical generalizability of the findings. This research's exploratory aim meant that to achieve greater depth in exploration, breadth was sacrificed. However, the exploration's depth allowed the researchers to begin from detailed descriptions and conceptualize, generate specific insights and insights (Lee et al. 2003). Furthermore, the limited knowledge of congestion factors meant that quantitative approaches were generally less suited for the exploratory task, as they generally require a pre-existing conceptual framework.

Nonetheless, the findings of this research are expected to be useful both in the context of other bulk and container terminals and supply chains, irrespective of their proximity to large urban areas. Many bulk cargo export supply chains share similar features to the supply chains investigated in this research – unidirectional, highly fragmented, involving multiple participants with potentially conflicting interests whose operations intersect at a port and managing a commodity product. Given these similarities, it is expected that the congestion factor model will be highly relevant to researchers and practitioners investigating these supply chains. Container terminals and supply chains present additional complexity. Consequently, it is anticipated that the model can provide guidance to researchers and practitioners investigating congestion and may need to be extended with aspects specific to containerized operations.

Future research aims to use the congestion factor model developed in this work to assist in developing and implementing measures to mitigate congestion in bulk cargo terminals.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Semi-Structured Interviews Question Frame

The question frame used during the interviews was divided in 5 categories of questions:

- 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 the respondents' incentives and responsibilities with respect to the company's general operations. Initial questions in this category revolved around the company's general operations, whilst subsequent questions narrowed-down on the specific tasks of the respondent.
- Information and technology related 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.
- Congestion management 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.

The question frame for the evaluation 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 participatory design workshops from the respondents' viewpoints.

- Questions regarding the implementation and impact of congestion mitigation 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.

  Congestion Factors
  Table 2.

Table 2
Congestion factors core category - axial and open codes

Open Codes	Axial Code	Core Category
centralized 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	Limited Coordination	Congestion Factors
"inside vs outside", "the boat might not come back", competitive behavior, 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	Interdependence of Operations	
"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 utilization, it's more of an inconvenience, misaligned management decisions, no legal authority, optimal capacity, optimal truck flows, profit focus, profit vs value add, throughput increase, throughput standard maintained, vested interest	Misaligned Incentives	
"Bigger isn't always better", contractual nominal terms, meeting contractual performance threshold, terminal unloading procedure, turnaround time expectation, turnaround times, unloading staff performance	Performance Expectation	
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	Infrastructure Limitations	
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	Supply Chain Flexibility	
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	Operational Disruptions	

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