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Exploring Congestion Impact Beyond the Bulk Cargo Terminal Gate

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Bulk cargo terminal congestion management, approaches have tended to be almost exclusively focused on the sea side of bulk terminals. To-date there has been very limited work on land-side approaches to mitigate congestion in bulk terminals. This research aims to address these gaps by considering the effectiveness of multiple congestion management methods across a range of throughput scenarios. This paper develops a discrete event simulation model based on data collected from an Australian bulk wood chip export maritime terminal and analyses the effect of infrastructure and process improvements on gate congestion and hinterland logistics chains. The improvements include: variations of terminal configurations, a terminal appointment system and gate automation technology. This paper argues that traditional efficiency and utilization measures fail to capture the impact of these alternatives over the whole hinterland logistics chain. Results indicate that the gate automation technology and the introduction of an appointment system can reduce average turnaround times by approximately 20%. Interestingly additional unloading capacity has a relatively small influence (<10%) on the average turnaround time under the initial truck arrival frequency. Significantly, findings highlight how the range of alternatives that improve efficiency and utilization can be impaired when organizations do not plan and negotiate impacts with other terminal users along the hinterland logistics chain. The impact of these alternatives needs to be evaluated in the broader hinterland perspective to enhance stakeholder 'buy-in' and resilience over time of solutions implemented.

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1 Introduction

Research on bulk cargo terminals congestion management has tended to be limited to approaches that improve sea-side and yard capacity to minimize vessel delays and associated costs. On the land-side, there is an inherent logic, from a terminal perspective, that a certain level of congestion is beneficial to maintaining a high level of equipment efficien y and utilization. Terminals may therefore have little incentive to address congestion, particularly when no financial penalties are applied for exceeding turnaround time thresholds. Counterintuitively, congestion can reach levels where it creates difficultie for terminals to evaluate strategic development options and, more prosaically, to plan maintenance works. From a terminal user and hinterland logistics chain perspective, the impact of congestion and mitigation methods is also typically neglected.

In this context, this research introduces a discrete event simulation model based on a case study of a bulk maritime terminal in Australia and investigates the effect of multiple approaches on mitigating congestion and the terminal and the hinterland logistics chains. Previously, the potential impact of a terminal appointment system and automation technology under existing throughput conditions was explored (Neagoe et al., 2018). This paper extends the investigation with updated data, additional development options and an evaluation of hinterland logistics impact and approaches' robustness under increased throughput conditions.

1.1 Case Description

The bulk cargo terminal on which the case study is based operates in a medium sized Australian port and is open 24-hours per day. The terminal is an export facility for wood chips, a processed timber product. Wood chips are the raw material input in paper production or used as biofuel.

The terminal receives deliveries of wood chips regularly from three processing facilities located at various distances from the terminal. Logs from the forest harvesting sites are delivered to the three facilities. The logs are processed into wood chips at the mills and then stockpiled. Dedicated trucks are loaded with wood chips from the milling site and then drive to the terminal in a cyclical delivery operation. Approximately 60% of trucks have an average delivery cycle (excluding the terminal unloading) of 40 minutes, 35% drive and load in approximately 90 minutes and the rest of 5% drive and load in 300 minutes. Trucks operate in 12 hour shifts during which they try to maximize the number of deliveries to the terminal. The relatively close proximity between the processing mills and the terminal means significant changes in the terminal turnaround time can impact on the efficien y and utilization of the transporters' equipment and the chain as a whole.

Two types of wood chips are delivered to the terminal. These are stored in separate stockpiles and cannot be mixed. Wood chips are delivered to the terminal and stockpiled, until sufficien volumes are available to fill a wood chip vessel bound for export markets. On average, between 1,500 and 2,000 truck loads are required to reach the volume capacity of a vessel.

The terminal unloading process starts at the weighbridge where the trucks are weighed. Drivers are then directed to the wharf area where they wait until an unloading ramp is available. Two unloading ramps operate at the terminal. Wood chips are unloaded from truck trailers using hydraulic ramps that lift the entire body of the truck, forcing the product out the trailer doors. Concurrent unloading can take place if the bin in which product is unloaded has sufficien space available, and if two trucks carry the same product. A conveyor belt system connected to both unloading ramps moves the product from the bin to the stockpile. Once unloading is finished, drivers weigh their trucks once more at the weigh-bridge. The difference between the first gross-weight reading and the second empty-weight reading is the net weight of the product delivered. The time between weight readings is the truck turnaround time. Upon completing unloading, trucks return to the milling facilities and, the delivery cycle is restarted.

On average, trucks arrive at the terminal every 10 minutes. Figure 1 shows the observed arrival distribution of trucks. The distribution is right-skewed. Approximately 60% of arrivals are less than 10 minutes apart and more than 30% are less than 5 minutes apart. Although the average terminal turnaround time of trucks is approximately 22 minutes per truck, 40% of the turnaround times are larger than the average and can reach 120 minutes in some cases. The clustering of truck arrivals at the terminal therefore introduces significant inefficiencie in the system, although the terminal enjoys a relatively good capacity utilization. Partly due to irregular and clustered arrivals, the terminal is currently experiencing severe congestion at the gate and unloading facilities.

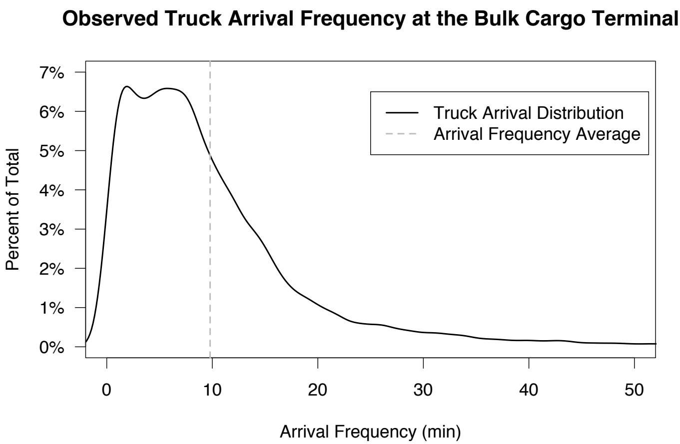

Figure 1: Observed truck arrival frequency at the bulk cargo terminal

2 Literature Review

Research on bulk terminal gate congestion applications is relatively limited. Considerably more effort has gone in research on congestion management in container terminals. Bulk cargo terminals modelling literature, together with modelling and applications of congestion management techniques in marine container terminals are briefly reviewed below.

2.1 Bulk Cargo Maritime Terminals

Dry bulk terminals can be split into two categories: export and import terminals (van Vianen, Ottjes and Lodewijks, 2014) and generally serve only one of the two functions. Much of the dry bulk terminal research reviewed focused on commodities such as: coal (Wadhwa, 1992, 2000), iron (Van Vianen et al., 2012; Bugaric and Petrovic, 2007; Bugaric, Petrovic and Jeli, 2015) or bauxite (Cimpeanu et al., 2015; Cimpeanu, Devine and O'Brien, 2017). The main issues explored in the dry bulk terminal literature reviewed are regarding vessel handling and yard capacity of the terminals (Cimpeanu, Devine and O'Brien, 2017; Dahal et al., 2003; Bugaric and Petrovic, 2007).

Bugaric and Petrovic (2007) investigate the effect of vessel unloading mechanization at an iron and coal river terminal. Their results, obtained using a discrete time simulation model, indicate that this approach can improve unloading times and therefore reduce the penalties associated to vessel waiting times (demurrage). Wadhwa (2000) investigate deploying additional vessel loaders at a bulk export facility to improve the vessel handling capacity of the terminal. Findings from the discrete event simulation model indicate that an additional vessel loader can increase the terminal's capacity by more than 20%. The deployment of an additional loader is motivated by vessel loading time requirements and penalties associated with waiting times. Financial penalties are one of the most frequently mentioned reasons for optimizing and improving the loading or unloading process at terminals.

Timber products, such as logs or wood chips, can also be transported in bulk. Munisamy (2010) analyzed the capacity of a timber products export terminal in Malaysia and found that balancing the available equipment capacity in each stage of the loading process at the terminal is crucial to maintaining a consistent throughput and utilization. Their research focuses on yard management and vessel loading processes and made little mention of the terminal gate and product deliveries. The authors were unable to identify research centered on wood chip export terminals from a logistics perspective.

Throughput capacity increases on the sea side are not always met with a similar approach on the land side. Several reasons can be identified: (1) export dry bulk terminals are commonly supplied by train (van Vianen, Ottjes and Lodewijks, 2011); (2) import terminals are typically closely located to production facilities (such as steel mills) or power plants and provide continuous supply of raw materials via conveyor belts; (3) some authors hypothesize that terminal gate operations, although important, are simpler to handle logistically and cost-wise as long as the main performance indicator, vessel waiting time, is satisfactory (Bassan, 2007).

This paper however argues that the land-side interface is just as important as the sea side. The incoming throughput of a terminal equals the outgoing volumes. Therefore, one of the main factors determining a terminal's throughput is the lowest common denominator between the terminal gate, berth and storage capacity.

Furthermore, the task of coordinating multiple stakeholders with multiple, often diverging interests, is similarly complex on the land as on the sea side.

A limited number of papers deal with terminal gate congestion in the context of bulk terminals and particularly for wood chips. The container terminal literature is significantly richer and identifies and evaluates a number of approaches to mitigate terminal gate congestion. As both containerized and bulk transportation share a number of similarities (Bugaric, Petrovic and Jeli, 2015), the insights gained in containerized terminals are of relevance in the context of bulk goods.

2.2 Terminal Gate Congestion Management

Terminal gate congestion mitigation approaches can be distinguish on two planning and control levels. On the strategic level, capacity can be increased over time. On the tactical and operational levels, gate operating hours can be extended and terminal appointment systems (TAS) can be introduced (Maguire et al., 2010). Additional alternatives that can facilitate and support the introduction of congestion management tools include gate automation technologies via Optical Character Recognition (OCR) or Radio-Frequency Identification (RFID) systems (Heilig and Voß, 2017) and congestion pricing.

Extended gate working hours increase the number of available delivery times for trucks (Giuliano and O'Brien, 2007) and can help smooth truck arrival peaks. TAS define delivery or pick-up slots for transporters and aim to manage arrival patterns of trucks. This approach requires limited capital and human resources expenses and has the potential to improve terminal and gate operations, decrease roadway congestion and reduce green-house gasses emissions (Maguire et al., 2010). Congestion pricing introduces incentives for delivering at less busy times (Bentolila et al., 2016) or disincentives for deliveries during peak hours (Holguín-Veras et al., 2011) in an attempt to shift traffi patterns. Gate automation technologies can be used in combination with other congestion relief methods to reduce manual input from drivers and enhance terminal security.

A common feature of the literature surveyed is that the perspective of the terminal is frequently taken when reporting results, whereas the impact of the method on transporters or the logistics chain is often disregarded (Huynh, Smith and Harder, 2016). Huynh (2009) use discrete event simulation to investigate the impact of different scheduling rules of TAS and maximize the utilization of unloading equipment in the terminal. Their results indicate that an individual appointment system leads to lower equipment utilization and a reduction truck turnaround times. Similarly, the impact of variations of TAS rules on yard efficien y are evaluated by Zhao & Goodchild (2013) using simulation and queuing theory. Their findings indicate that system performance can be significantly improved even with imperfect information on truck arrival times. This finding is supported by Chen, Govindan and Golias (2013). The authors use a queuing model to optimize truck waiting times and find a reduction of approximately 50% in congestion when arrivals during peak times are spread (Chen, Govindan and Golias, 2013). Huynh & Walton (2008) and Ambrosino and Caballini (2015) use simulation to reduce yard congestion in order to meet service level requirements of trucks. This means however that the waiting times of trucks outside the terminal gates are not considered. Terminals actively sought to reduce vessel waiting time prior to loading or unloading to avoid penalties. For trucks, waiting times outside terminal gates are often times disregarded. While outside the terminal, trucks are on the public domain and their waiting time may not be as easily quantified. Furthermore, the unique inter-organisational relation between terminals and drayage companies where, often times, no contractual arrangement exists between the two parties (Jaffee, 2016), can lead to a lack of focus on the efficien y of the overall land transport task and terminal interface cost.

One attempt of combining the perspectives of terminals and transporters was taken by Guan and Liu (2009). Terminal operations were represented by a queuing model and an optimization model was used to minimize the truck waiting and gate operating costs. The optimal arrival pattern produced 35% less congestion that the initial situation. The largest cost reduction resulted from a decrease in truck waiting times. Zehendner and Feillet (2014) modelled a TAS and included delay costs for trucks, trains and barges in their optimization model of a container terminal. Their results indicate an average reduction of approximately 14 minutes in the optimal solution. One disadvantage of pooling terminal and truck costs together into one cost measure is that the optimization model solution may be sensitive to variations in cost ratios. In their study, Guan and Liu (2009) used an hourly gate-truck operating cost ratio of approximately 4 to 1. If a broader perspective on supply chain costs is taken, the ratio is likely to decrease.

One explanation for the strong preference for TAS in the research literature is that this approach is ”less disruptive and less costly than extended gate hours” (Giuliano and O’Brien, 2007). However, this argument fails to account for the decreased flexibility for truck operators and the impact on their fleet productivity and utilization (Ramírez-Nafarrate et al., 2017). It also further highlights the terminal-centric approach to managing gate congestion. Noticeably, studies evaluating variations of appointment systems or congestion pricing, few if any, have compared the impact of different congestion mitigation techniques. Spreading arrivals at terminals helps reduce delays, however scenarios and benefits of mechanisms to tackle congestion that affect multiple port users do need to be analysed prior to implementation (Ramírez-Nafarrate et al., 2017).

3 Bulk Cargo Terminal Simulation Model

Simulation is one of the most frequently used modelling techniques, along with queuing and optimization models, for investigating congestion management. Simulation can be an effective tool to understand the impact of a limited number of variables on the system modelled (Manuj, Mentzer and Bowers, 2009) and allow researchers to develop and analyse ”what-if” scenarios (Crainic, Perboli and Rosano, 2017). This research utilizes a discrete event simulation approach to model a bulk terminal gate and the implementation of congestion management measures adapted from container terminal literature. The measures impact on the terminal and the logistics chain is evaluated, as well as their performance when the terminal throughput increases.

3.1 Model Specification

The model’s **input data** originates from two sources: the weigh-bridge soft are generates reports containing truck arrival and departure times, gross and net weight readings and products delivered. A sample containing 9 months of truck arrivals was used for this model. The duration of each stage of the unloading process (weighing, unloading, drive times and final weighing) was determined by geo-fencing the location of each stage and measuring the visit duration. This was achieved using GPS data from one trucking company. The GPS information covering approximately 15,000 truck trips spread over 3 months were analysed.

The simulation model is based on the following **assumptions**: (1) Two products are delivered concomitantly at the terminal and cannot be mixed during unloading or during storage; (2) Two types of trucks deliver product at the terminal; (3) The terminal operates non-stop during the simulation, no breakdowns or terminal closures are modelled; (4) Two unloading ramps with the same capacity operate at the terminal; (5) Truck turnaround times are measured from weigh-bridge (gross-weight reading) to weigh-bridge (empty-weight reading); (6) The weighing in stage is the entrance of the truck in the system therefore, the weighing-in duration and queuing time are excluded from the turnaround time calculation. The simulation **model logic** follows the unloading process described in the introduction and is detailed in Figure 2.

The model was implemented in Python. Arena Input Analyzer was used to fit the input data to distributions. The distributions that best fit the empirical data were used as the **model's parameters**: (1) One truck type can load maximum 32-tons of product and the payload distribution is described by a +19 shifted beta distribution with parameters $\alpha = 9.77, \beta = 6.55$; (2) The second truck type can load a maximum of 45 tons and its payload distribution is described by a normal distribution with parameters $\mu = 38.7, \sigma = 1.18$; (3) The inter-arrival time is described by a gamma distribution with parameters $k = 1.49, \theta = 6.97$; (4) Unloading the same product at two different ramps can take place if one ramp has completed more than 60% of its unloading cycle before the other begins. A different product can be unloaded if one ramp has completed more than 80% of its unloading cycle before the other begins; (5) The unloading times are described by a lognormal distribution with $\mu = 5.16, \sigma = 3.97$; (6) The driving time between the weigh-bridge and the unloading ramps is held constant at 1 minute on arrival and 2 minutes on departure; (7) The weigh-bridge operation time is described by a normal distribution with parameters $\mu = 3.46, \sigma = 1.68$;

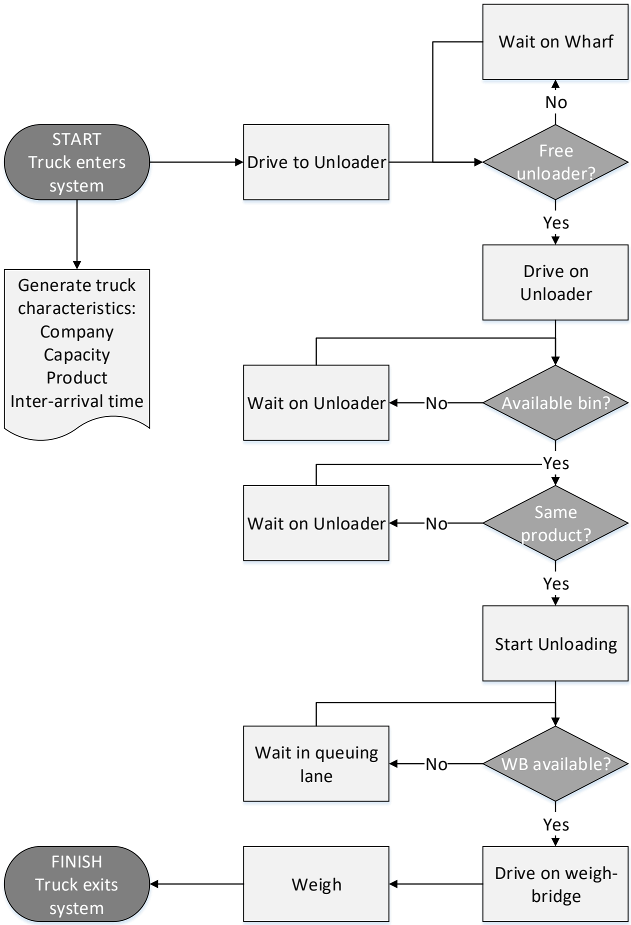

Figure 2: Terminal simulation model logic

3.2 Simulation Results

Four congestion management methods were explored under four truck arrival frequency scenarios. The starting arrival frequency was a gamma distribution with parameters $k = 1.49, \theta = 6.97$ with an average of one truck arrival every 10 minutes. Subsequent scenarios applied decreasing multipliers: 0.9, 0.8 and 0.7 respectively to simulate increased traffi under the same distribution. The terminal appointment system (TAS) included slot intervals equal to the average arrival frequency of trucks for other methods (10 minutes in the base case). Slot intervals were scaled down as traffi increased. The congestion management methods considered include two tactical approaches and two strategic level capacity improvements:

Terminal appointment system (TAS). Trucks currently arrive unscheduled at the terminal. Arrivals can be more evenly distributed using individual slot appointments for each truck. Trucks are scheduled to arrive at regular intervals and, should arrive between the last arrival and the next slot. A stochastic component drawn from a normal distribution with $\mu = 0, \sigma = 2.5$ modelled delays or early arrivals of truckers compared to their scheduled arrival time.

Gate automation technologies simulate the reduction of weighing processing times. Currently all trucks delivering at the terminal are weighed after delivery to calculate the net weight of the payload. The automation technology eliminates this stage by using digitally stored truck tare weights.

Extend the unloading system with an additional ramp with the same characteristics as existing unloading equipment is added to the existing conveyor belt system.

Expand the unloading system with a separate unloading ramp and conveyor system for one stockpile. This separates the two products flows and eliminates the risk of product contamination. It also substantially increases the system capacity, as unloading can now take place concomitantly irrespective of the products delivered.

For comparison purposes, the alternative of **not intervening** with a congestion management approach is also presented.

Each arrival frequency scenario and congestion management approach combination is simulated 1,000 times. The values presented are the averages over the iterations. Each iteration represents 365 days of operations.

Table 1: Simulation model outputs for 10-minute average arrival frequency scenario

Model Output	TAS	Automation Tech.	Expand Unload System	Extend Unload System	No Intervention
T. Time (min)*	17.47	18.00	20.22	21.78	22.12
W. Time (min)**	1.59	5.68	4.49	5.99	6.31
Throughput(t)	1,604,131	1,598,892	1,599,670	1,599,782	1,599,389
Trucks	52,559	52,389	52,415	52,414	52,402

*T. Time = turnaround time, **W. Time = waiting time

Table 1 illustrates the simulation model results for **the first scenario** which simulates a 10-minute average truck arrival frequency. Two methods stand out as particularly effective, the automation technology and the TAS. Both can reduce average turnaround times by approximately 20% (from 22 to 18 minutes) compared to no intervention. While the reduction in turnaround times is similar, the ways the two methods achieve this reduction are different. The automation technology reduces operational time, while the TAS substantially reduces the truck waiting time. Additional unloading capacity has a relatively small influence, less than 10% reduction of the turnaround time.

Figure 3 illustrates that, while differences in averages may not be substantial, the turnaround time distributions are significantly different. The reduction in average turnaround times with the TAS and the expanded unloading system is caused by a reduction in variance. The automation technology reduces operational times and therefore shifts the turnaround time distribution to the left, leaving its structure intact. The extended unloading system is excluded from Figure 3 because it substantially overlaps with the no intervention case.

Subsequent arrival frequency scenarios included average arrival frequency times of 9, 8 and 7 minutes. To conserve space, only the 7-minute case is pre-

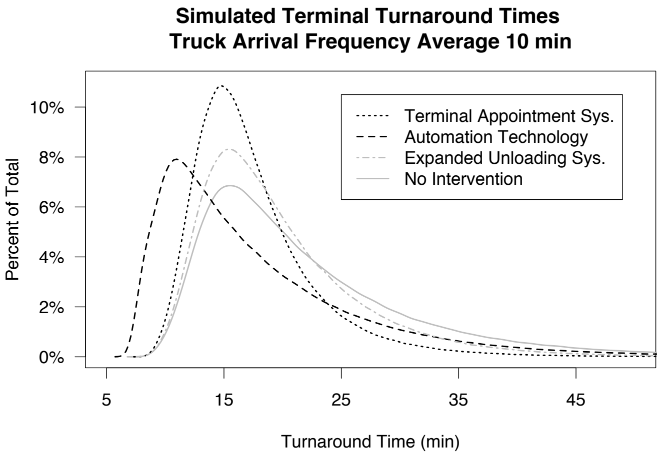

Figure 3: Simulation model turnaround times distribution for 10-minute average arrival frequency scenario

sented in table 2. The no intervention and automation technology approaches evolve in a similar manner. The 4-minute difference in turnaround time is maintained, however waiting times remain very similar. Until a throughput of 2 million tons is reached, the unloading system expansion also follows a similar trend in terms of turnaround times, showing little impact on turnaround times. At a 2.3-million-ton yearly throughput, waiting times increase dramatically. Likely, capacity utilization reaches a level where additional trucks can destabilize the system and increase waiting times dramatically. At the same time, both the TAS and the expanded unloading systems are more robust to changes in throughput. In the 7-minute average arrival frequency scenario, both methods are 65% more effective on average than the no intervention case.

Figure 4 shows a similar pattern of distribution variance reduction for the TAS and the expanded unloading system as in previous examples. In contrast, the automation technology and extended unloading system maintain the shape of the turnaround times distribution while shiftin its peak. Clearly, increased vol-

Table 2: Simulation model outputs for 7-minute average arrival frequency scenario

Model Output	TAS	Automation Tech.	Expand Unload System	Extend Unload System	No Intervention
T. Time (min)	30.12	78.51	26.26	62.62	83.52
W. Time (min)	14.41	66.22	10.73	46.94	67.83
Throughput(t)	2,291,889	2,311,094	2,312,181	2,312,982	2,311,706
Trucks	75,082	75,722	75,756	75,787	75,731

umes put a strain on the terminal, however, the effectiveness of the approaches modelled in reducing average turnaround times differs significantly.

An evaluation of the impact of congestion management approaches on terminal users and the logistics chain is a more complex task. If the average delivery cycles and average terminal turnaround times are considered, the truck productivity decreases by almost 45% in the no intervention approach between the 10 and 7 minutes arrival frequency scenarios. In the 10-minute arrival frequency scenario, the TAS and automation technology approaches could improve truck productivity by up to 15% compared with no intervention. In the 7-minute arrival frequency scenario, the TAS and expanded unloading system could improve productivity by up to 40% compared with no intervention. However, average values do not provide an accurate picture of the actual impact on the users, as they fail to account for the variables' distributions and should only be used as trend indicators rather than predictors.

A central argument of this research is that efficien y and utilization measures may fail to capture two important aspects: first, the congestion management approaches' robustness to changing traffi and second, the congestion management intervention or lack thereof impact on the hinterland logistics chains. The implications of this narrow lens are explored in the next section.

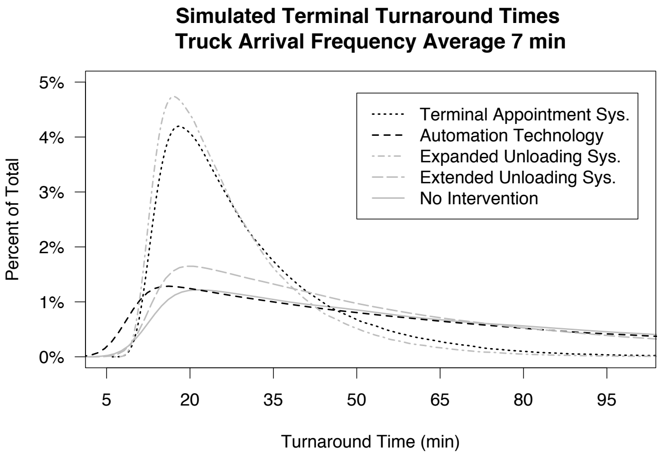

Figure 4: Simulation model turnaround times distribution for 7-minute average arrival frequency scenario

4 Discussion

The search for operational efficiencie and capacity improvements is an ever-present theme in the terminal modelling and applications literature. This research suggests that a unidimensional measurement of congestion management techniques impact may be an oversimplification. Automation technologies can eliminate process or cargo handling time. In the 10-minute average arrival frequency scenario, the reduction was approximately 20% compared to the no intervention. At the same time however, *this improvement exhibits decreasing returns with increased traffic*. As terminal asset utilization increases, waiting times follow a similar trajectory therefore reducing the relative benefit of operational improvements.

A terminal appointment system (TAS) is clearly one of the lowest cost and potentially highest impact congestion mitigation solution. This approach requires the highest degree of coordination and collaboration between users and terminals. The modelled impact of the TAS is based on a series of assumptions on the technical feasibility, stakeholders' willingness to collaborate and the static nature of the environment (Neagoe et al., 2018). This research has partly relaxed the assumption of static nature by evaluating the TAS robustness under various throughput scenarios. The technical feasibility may not pose significant difficultie however, attracting support from stakeholders may prove challenging. Evaluations of TAS usage in previous studies have shown lower than expected usage if the solution is deemed incompatible with transporters' business requirements (Morais and Lord, 2006) or the system is perceived as an attempt to take advantage of the transporters (Davies, 2013).

The congestion management methods introduced appear to have limited impact for the terminal's costs or efficien y, particularly when no penalties are imposed for exceeding a set turnaround time threshold. *Terminals have little incentive to address congestion as it can be perceived as an alternative to maintain high levels of equipment utilization. Issues arise when strategic investments for capacity expansion or maintenance works planning are considered*. High asset utilization may create a perceived urgency to expand capacity to accommodate demand. However, the effectiveness of additional equipment to mitigate congestion issues is highly dependent on whether it addresses the actual operational bottleneck. Furthermore, maintenance planning becomes increasingly problematic with sustained levels of congestion as high utilization implies high demand and little downtime. Postponed maintenance can increase the probability of catastrophic failures which can severely impact both the terminal and its users.

Terminal users also experience a set of challenges related to congestion. Terminal service time uncertainty may translate into an upstream 'bullwhip effect' (Lee, Padmanabhan and Whang, 1997). Symptoms of uncertainty may include forecast inaccuracy, excessive inventories and high inventory turn times (Maleki and Cruz-Machado, 2013). Ultimately the effects of a high uncertainty environment can impact the supply chain's profitability. At an individual driver level, the risk of fatigue may increase as the flexibility to choose breaks decreases (Perttula, Ojala and Kuosma, 2011). Furthermore, congestion effects may not be equally spread amongst port users. Consequently, transporters may attempt to find alternatives to improve their effici ncy, often at the expense of the other users. Conversely, decreased turnaround times may facilitate the chain's resilience. At a transporter level, schedule and fleet management can be improved (Huynh, 2009).

The range of impacts and behaviours discussed cannot be easily encompassed in existing methods of measuring efficien y and utilization. As links in the logistics chain are studied in isolation, the intricate interdependencies between them are obscured. The modelling approach only allows for the subset of behaviours that can be captured, quantified and geo-located to be modelled. Consequently, a broader lens that acknowledges multiple stakeholder perspectives and objectives and, the impact of interdependent links in the logistics chain is required to best optimize synergies between the various components in the chain.

5 Conclusion

This research adapted gate congestion management methods from container terminal to a bulk cargo marine terminal. A discrete event simulation model based on a wood chip export terminal in Australia was developed to evaluate the different methods' impact on terminal turnaround times and on the hinterland logistics chain.

Simulation results indicate that both automation technologies and a terminal appointment system can reduce average turnaround times by approximately 20% (from 22 to 18 minutes) compared to no intervention. Additional unloading capacity has a relatively small influence, less than 10%, on average turnaround times. With increased volumes, automation technologies and unloading capacity extension generate fewer benefits. The terminal appointment system and the unloading capacity expansion appear to have a significant impact in managing terminal gate congestion.

Automation technologies and additional infrastructure that target improvements in terminal efficien y may fail to yield expected results if they do not address the actual operational bottleneck. The lowest cost option, the terminal appointment system, may come with the highest requirements, in terms of stakeholder collaboration, that need to be satisfied to achieve its full potential.

The range of impacts and behaviours discussed cannot be easily encompassed in existing methods of measuring efficien y and utilization. As links in the logistics chain are studied in isolation, the intricate interdependencies between them are obscured. Consequently, a broader lens that acknowledges multiple stakeholder perspectives and objectives and, the impact of interdependent links in the logistics chain is required to best optimize synergies between the various components in the chain.

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http://www.utas.edu.au/arc-forest-value

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