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Research in Progress

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Abstract

This research-in-progress paper is part of an ongoing investigation that explores the role of information and digital systems for understanding congestion challenges and management approaches in bulk cargo marine terminals and supply chains. This paper contributes to the broader investigation by developing a discrete-event simulation model to improve understanding of the impact of driver behaviors and scheduling parameters in the use of a digital terminal appointment system on truck flows in the supply chain and turnaround times at the terminal. The data supporting the simulation model was collected from an RFID-enabled weigh-bridge system of an Australian terminal operator and GPS units mounted on trucks. Simulation results indicate that even low levels of system use can reduce truck turnaround times and reduce service time uncertainty. Interestingly, the truck turnaround time benefits resulting from the use of the appointment system are particularly significant when the terminal operates at high capacity.

Keywords: Terminal appointment system, congestion management, digital systems, transport management, logistics chains

1 INTRODUCTION

Digital terminal appointment systems are one of the most effective truck coordination and congestion management technologies. Whilst their potential to significantly reduce truck turnaround times has been analytically confirmed in multiple research studies (Guan and Liu 2009; Huynh 2009; Li et al. 2018; Torkjazi et al. 2018), appointment systems appear to have had less-than-expected impact in empirical applications (Davies 2009; Giuliano and O'Brien 2007). Some of the reasons for the less-than-expected impact include user behavioural issues such as system abuse and misuse (Morais and Lord 2006). These behaviours reduce the effectiveness of the system by encouraging its exploitation. Penalties levied on users for delayed arrivals and missed appointments can also act as a deterrent for system use, if unappointed arrivals are allowed. Alternatively, if appointments are mandatory, penalties can become a revenue source for terminals (Davies 2009). However, turning penalties into a revenue stream can direct terminal efforts increasing revenue rather than improving discipline amongst users. Both user behaviours and system parameters can influence the effectiveness of digital appointment systems, however it is unclear what impact these factors can have on truck turnaround times and on the truck flows within their respective supply chains.

Analytical approaches are often used to determine the optimal system parameters and the influence of user behaviours on the system's performance. System parameters can include the number of appointments per time-window (Torkjazi, *et al.* 2018; Huynh and Walton 2008) or the lead time for selecting an appointment time and truck servicing rules (Li *et al.* 2018) . User behaviours can be modelled by the probability that drivers miss appointments, arrive un-appointed (Huynh and Walton 2008), or their arrival punctuality (Li, *et al.* 2018; Ramírez-Nafarrate *et al.* 2017). These parameters are generally determined by optimization approaches, either linear programming (Chen and Jiang 2016), queuing theory (Guan and Liu 2009) or through simulation (Huynh and Walton 2011). However, the influence of users' behaviours and parameters on the effectiveness of digital appointment system has not yet been addressed. As a result, most research has advocated the use of penalties to enforce compliance with the appointment schedules (Ramírez-Nafarrate *et al.* 2017). Alternatively, more complex truck service rules can be introduced to ensure a performance as close to optimal is achieved (Li *et al.* 2018).

This research therefore improves understanding regarding the impact of parameters related to driver behaviour (punctuality and proportion of planned appointments) and temporal scheduling (appointments per time window) on truck flows in the supply chain and turnaround times at the terminal through the use of a discrete event simulation model of a bulk cargo marine terminal. The modelling results be used in the broader investigation to facilitate mutual understanding and learning amongst stakeholders with regards to the impact of their behaviours and system parameters on the effectiveness of digital technologies used to manage congestion.

2 THE WOOD CHIP EXPORT SUPPLY CHAIN

The raw material production, primary processing and transfer stages of wood chip export supply chain used as a case study for this research are located in Australia. Hardwood logs harvested from forests are delivered by log trucks to processing facilities, manufactured into wood chips and temporarily stored. The processing facilities are located in a relatively close proximity to the export terminal. The wood chips are transported between the processing facilities and the terminal by truck. Wood chips are stored at the export terminal and are subsequently loaded on board vessels and transported for secondary processing by international pulp and paper producers. The supply chain presented in Figure 1, handles approximately 1.6 million tons of wood chips per year, and the terminal facility received approximately 52,000 truck visits per year.

Figure 1: Wood chip supply chain

Log harvesting, wood chip manufacturing and transportation are managed by 2 forestry companies that use contractors for individual activities. One of the forestry companies manages the wood chip manufacturing process internally. The other uses an external contractor. The wood chip manufacturing is performed in specialized mills located approximately 90 and 30 minutes respectively from the export terminal. Each forestry company uses a transport contractor to deliver wood chips to the export terminal. This creates a relatively closed transport system that is exposed to little interference from external parties. Nevertheless, the supply chain was experiencing significant congestion, particularly at the export terminal. As a result, transporters faced increasing costs, decreased asset productivity and service time uncertainty. The forestry companies faced increasing operational uncertainty and risk of potentially costly delayed vessel loadings. The terminal operator was also facing increased costs and maintenance scheduling challenges.

The terminal operator, forestry companies and transporters considered a series of potential options to mitigate congestion. Given that congestion was most visible at the terminal, the terminal was considered the best location to start mitigation efforts. The terminal operator, in particular, expressed interest for the implementation of an appointment system to manage transport flows between the production sites and the terminal. However, the forestry companies and transporters had a series of concerns regarding the system, mainly: the impact it would have on the supply chain, the parameters used and how these factors could affect the control of one party or another over the transport flows and the impact of driver behaviours, primarily system usage, on the effectiveness of the system. The researchers developed a simulation model of the export terminal to improve understanding regarding the potential impact of different system parameters and behaviours can have on truck waiting and turnaround times and ultimately inform the stakeholders' investigation into the development of an appointment system solution.

3 DATA COLLECTION AND SIMULATION MODEL

The simulation model's scope covers the truck unloading operation at the export terminal. The supply chain is significantly larger and more complex. However, the availability of accurate and useful data throughout the supply chain limited the scope of the model. The smaller scale and limited complexity allowed however for a large number of 'what-if' scenarios to be generated.

The majority of data in the supply chain is collected using weigh-bridges, generally located at the entrances and exits of various facilities, including the export terminal. The terminal weigh-bridge records were made available for the research team (Approximately 15,600 records covering 7 months). The weigh-bridge system is operated using RFID tags. When trucks arrive on the entry weigh-bridge, the truck details, arrival timestamp and gross weight are recorded. The exit weigh-bridge visits record the empty weight of the truck and departure time and reconciles the vehicle identification with the existing details in the database. On the terminal premise, trucks wait in a marshalling area for unloading and are unloaded using two hydraulic ramps. The duration of individual stages could not be measured using the existing information system.

One of the transport operators used global positioning systems (GPS) units mounted on their trucks that recorded their position. The operator also marked geo-fences on the terminal premise to measure the time trucks spent in each area. These data consisted of approximately 6,700 geo-fence entries for each area of interest (unloading ramps, entry weigh-bridge and exit weigh-bridge) and allowed the research team to gain a better understanding of the duration of individual unloading stages at the terminal. The weigh-bridge and GPS data were supplemented by on-site visits by the research team, both at the terminal and along the supply chain to ensure that important aspects are captured, or that their potential influence on terminal operations is understood. The quantitative data collected was analysed using Arena Input Analyser to generate distributions that would then form the input for the simulation model.

The 2-phased simulation model includes a truck arrival generator function and a truck processing function. The model is implemented in Python programming language. The truck arrival generator function uses the planned arrivals parameter to indicate the percentage of appointed and unappointed arrivals. The truck arrival time is calculated based on the appointment status of each truck. The resulting truck arrival list is sorted in the ascending order of arrival times. A truck generator function creates truck objects for each entry on the list including the truck's capacity, payload, and product. The second phase of the model processes the trucks, simulating the terminal unloading process. The 2-phased approach was required as trucks are served on a first-come, first-served basis, irrespective of their appointment time. The trucks' characteristics and the service times of the terminal equipment – weigh-bridges and unloading ramps – are stochastically drawn from the distributions fitted from the geo-fence and weigh-bridge data. The entry weigh-bridge visit is held constant at 1 minute/truck. The driving times from the weigh-bridge and unloading ramp and back are held constant at 1 and 2 minutes respectively. The simulation model and its logic where presented and discussed with terminal staff to improve the accuracy and validity of the representation. Changes suggested by the staff were implemented accordingly and the model was iteratively refined.

The scenario analysis included driver behaviours factors (punctuality, missed and unplanned appointments) and system parameters (appointments per time window. The truck **arrival frequency** includes three appointment parameters for each one-hour time window, 6 (Low), 7 (Medium) and 8 (High). Where all trucks arrived unappointed, the truck arrival distribution used resembled that observed at the terminal; The **proportion of appointed arrivals** was gradually increased from 0% (all un-appointed arrivals) to 100% (all appointed arrivals) in 20% increments; The **truck arrival punctuality** was modelled by adding a stochastic component to each appointed arrival time using normal distributions, in a similar vein to Ramírez-Nafarrate *et al* (2017): (1) High punctuality: 95% of arrivals are within 5 minutes of the appointment time (2) Medium punctuality: 2/3 of arrivals are within 5 minutes of the appointment time (3) Low punctuality: 1/3 of arrivals are within 5 minutes of the appointment time. The scenario analysis included combinations of the 3 factors and resulted in 47 scenarios. Each scenario was run 20 times and each iteration simulated a year of operations.

4 PRELIMINARY RESULTS

The average truck turnaround times for the scenarios analysed are presented in Table 1. The first line in the table, where an average of 6 unappointed trucks arrive at the terminal each hour, resembles the empirically observed situation at the terminal. The following 5 lines in each scenario truck illustrate the simulation results of respectively 20, 40, 60, 80 and 100% appointed arrivals. Each increment in the proportion of appointed arrivals can improve average turnaround times by approximately 5% in the low arrival frequency scenario, close to 10% for medium and high arrival frequency scenarios. Interestingly, in the case of high arrival frequency, the first increment in appointed arrivals has the largest impact in reducing turnaround times.

App. Arrivals	App/ Hour	High Punctuality		Med. Punctuality		Low Punctuality	
		Avg. TT	TT Sd.	Avg. TT	TT Sd.	Avg. TT	TT Sd.
0%	6 (Low)	21.0	9.5				
20%		20.1	8.2	20.2	8.3	20.4	8.4
40%		18.8	7.0	19.1	7.1	19.6	7.5
60%		17.8	6.1	18.3	6.4	19.2	7
80%		17.1	5.6	17.7	5.9	18.8	6.7
100%		16.5	5.1	17.4	5.7	18.5	6.4
0%	7 (Med.)	24.8	13.2				
20%		23.0	10.5	23.2	10.7	23.6	10.9
40%		20.8	8.5	21.3	8.7	22.1	9.3
60%		19.3	7.1	20.1	7.7	21.4	8.5
80%		18.4	6.5	19.3	7.0	20.7	7.9
100%		17.7	6.1	18.9	6.8	20.4	7.7
0%	8 (High)	40.9	28.5				
20%		28.9	14.9	29.6	15.3	30.1	15.3
40%		25.2	11.5	25.9	11.7	27.4	12.8
60%		23.4	10.3	24.2	10.5	26.0	11.6
80%		22.1	9.5	23.0	9.7	25.2	11.0
100%		21.1	8.9	22.6	9.5	24.5	10.4

Table 1. Simulation results – Average turnaround times (Avg. TT) and standard deviation (TT Sd.)

The variability of turnaround times also decreases as the proportion of appointed arrivals increases. The variability of turnaround times, measured by the standard deviation, decreases in all three arrival frequency scenarios: For 6 trucks/hour, the decrease is approximately 40% between all unappointed and all appointed arrivals, close to 55% for 7 trucks/hour and approximately 66% for 8 trucks per hour. A lower truck arrival punctuality can translate into a limited reduction in turnaround time variability as the appointed arrivals proportion increases.

App. Arrivals	App/ Hour	High Punctuality		Med. Punctuality		Low Punctuality	
		App. Avg. TT	Unapp. Avg. TT	App. Avg. TT	Unapp. Avg. TT	App. Avg. TT	Unapp. Avg. TT
0%	6 (Low)	N/A	21.0				
20%		18.4	20.5	18.6	20.7	19.0	20.8
40%		17.6	19.7	17.9	19.8	18.5	20.4
60%		17.0	18.9	17.6	19.4	18.5	20.2
80%		16.7	18.5	17.4	19.0	18.5	20.1
100%		16.5	N/A	17.4	N/A	18.5	N/A
0%	7 (Med)	N/A	24.8				
20%		21.1	23.4	21.3	23.6	21.8	24.0
40%		19.5	21.7	19.9	22.1	20.8	23.0
60%		18.5	20.5	19.3	21.3	20.5	22.6
80%		18.0	19.9	19	20.8	20.3	22.3
100%		17.7	N/A	18.9	N/A	20.4	N/A
0%	8 (High)	N/A	40.9				
20%		26.5	29.5	27.3	30.2	27.7	30.7
40%		23.7	26.2	24.4	26.8	25.9	28.5
60%		22.5	24.7	23.3	25.5	25.1	27.5
80%		21.7	23.6	22.6	24.5	24.8	27.1
100%		21.1	N/A	22.4	N/A	24.5	N/A

Table 2. Simulation results – Average truck turnaround times for appointed (App. Avg. TT) and unappointed (Unapp. Avg. TT) vehicles

Both appointed and unappointed trucks can experience reductions in turnaround times at the terminal, with appointed trucks accruing more benefits. The average turnaround times of appointed and unappointed trucks in all scenarios are presented in Table 2. In virtually all the punctuality and appointed arrivals scenarios, appointed trucks have lower turnaround times. Lower arrival punctuality decreases the difference between turnaround times of appointed and unappointed trucks, however the differences continue to be significant in all cases. On average, appointed trucks can perform between 8-10% better when compared to unappointed trucks. Nevertheless, unappointed trucks also benefit from the increased proportion of appointed arrivals. The next section discusses the implications of this research in the context of the broader investigation and the extant body of knowledge.

5 DISCUSSION AND FUTURE RESEARCH

Modelling results reveal that a digital appointment system can help generate improvements in truck turnaround times also in low system use scenarios. One of the issues experienced by transport operators in existing implementations of appointment systems is that some users can abuse or misuse the system (Morais and Lord 2006) and 'free-riders', or users without appointments, can interfere with those that respect the system's rules. However, modelling results show that even small usage figures are sufficient to make an improvement. Interestingly, turnaround times are reduced for both appointed and unappointed trucks. Appointed truck arrivals generally have better turnaround times than unappointed trucks regardless of their punctuality. It is important to note that trucks were serviced on a first-come, first-served basis, irrespective of their appointment status. One issue transporters have highlighted in previous empirical studies was that no preferential service at terminals was provided for appointed trucks therefore limiting the drivers' incentives for using appointment systems (Giuliano and O'Brien 2007). This research highlights that there may be merit in using appointment systems even when preferential terminal service is not provided. While appointment systems may help generate truck turnaround time improvements, they may also generate benefits for the broader supply chain.

Increased use and punctuality of the digital appointment system are also associated with a decrease in turnaround times standard deviation and therefore service time uncertainty. In most appointment systems use scenarios, the standard deviation of turnaround times has consistently decreased as the use and punctuality have improved. Transporters can improve their ability to plan transport capacity and ensure the stability of their delivery patterns. This ability is even more important when evaluating the potential to perform additional deliveries towards the end of drivers' shifts. In situations where drivers have a limited number of driving hours remaining in their shift, the consistency of terminal service times can play an important role in determining the driver's compliance with national heavy vehicle regulations. Managing potential performance expectations of a digital appointment system for the terminal and stakeholders may not be sufficient to motivate use amongst transporters.

Technology use and adoption can also be influenced by its ease of use (Dwivedi et al. 2019). Whilst outside the scope of this paper, the researchers recognise the important role of the design and features of a digital appointment system to enable its integration in users' business processes and facilitate their acceptance of the technology. The involvement of appointment systems' users in functionality and features decisions has typically been limited (Huynh et al. 2016). This is likely one of the reasons for which some appointment systems implementations have failed to achieve the expected outcomes. The simulation results will play an important role in informing the next stages of the broader investigation which aim to understand the parameters, features and functionality of appointment systems that can improve their effectiveness and use.

6 CONCLUSION

This research-in-progress paper introduce a discrete-event simulation model to improve understanding of the impact of driver behaviors and scheduling parameters in the use of a digital terminal appointment system on truck flows in the supply chain and turnaround times at the terminal.

Modelling findings highlight the potential impact a digital appointment system can have on reducing truck turnaround times at export terminals and reducing uncertainty in supply chains even in cases of low system use. Importantly, simulation modelling can help shape performance expectations of users and, combined with a collaborative approach in determining the systems' parameters, features and functionality, can improve their effectiveness and use.

It is important however to acknowledge some of the limitations of the approach adopted in this research. Accurate and granular data prevented the researchers from expanding the model's scope beyond the terminal gate. The terminal stock management process, vessel unloading and also the transportation chain are processes which future research aims to encompass.

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