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Port terminal congestion management. An integrated information systems approach for improving supply chain value

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Abstract

The increasing size of freight vessels has influenced the volume and level of traffic congestion at land-side port terminals. Port responses impact on the socio-economic and environmental costs experienced in port hinterlands. In regional ports especially, these costs may have implications for regional development and the capacity of supply chains to retain and/or optimize value. Conventional port responses tend to adopt a narrow focus on terminal operations or on the potential benefits terminals and carriers can achieve through collaboration and integration. Few studies have adopted a supply chain perspective or examined how information systems may be used to balance competing user needs.

This research-in-progress paper highlights how a supply chain perspective deploying information systems can improve port congestion management by stimulating collaboration amongst multiple transport and terminal operators. Preliminary results show promise for the identification and delivery of an agreed solution to minimize port congestion and support value chain resilience.

Keywords Terminal appointment system, supply chain collaboration, maritime logistics

1 Introduction

Ocean going vessels have been increasing in size at a rapid pace over the last years (Mangan et al. 2008). This trend puts significant pressure on ports to accommodate larger vessels but also presents a challenge for hinterland port users. For every port call, the cargo must be delivered to and from inland locations, using truck, rail, or barge. The larger the vessel, the more the cost burden shifts from the sea side to the land side (Notteboom 2004). This holds true both for containerized and bulk supply chains. In regional areas with small port facilities these issues often become particularly problematic as small ports frequently have less flexible capacity to mitigate the worst effects of multiple, often fragmented smaller supply chain operations converging at the common point, the terminal gate.

Interestingly, despite this growing challenge of port congestion, there has been relatively limited academic or commercial research into how best to generate an integrated response. Indeed, there has continued to be a rather siloed approach with:

a) Shipping lines continuing to focus on minimizing operating costs by increasing the vessel size and optimizing their networks. This increases pressure on port infrastructure as more cargo is handled on each port call (Rodrigue and Notteboom 2009) and subsequently more land-side moves are required to transport the goods to and from their final destination;

b) Maritime port terminals, especially for containerized goods, continuing to focus on ways of competing and differentiating themselves from each other to attract shipping lines;

c) Terminals implement a wide array of internal management approaches to optimize use of infrastructure and equipment, especially at the port gate to manage land side congestion. These include terminal appointment systems, extended working hours, road pricing initiatives and investments in port infrastructure. Some approaches have been met with criticism because of lack of stakeholder engagement (Morais and Lord 2006) or attempts of the port industry to generate revenue from land-side users (Davies 2013).

A consequence of this siloed approach is that the negative implications of congestion for the supply chains and the environment of port hinterlands, especially at regional ports, has largely been ignored by port logistics research. This failure to understand and evaluate how contemporary terminal responses impact on regional development and on the capacity of local supply chain operators to retain and/or optimize value is a major concern.

This research-in-progress paper highlights how a supply chain perspective deploying information systems can improve terminal congestion management by stimulating collaboration amongst multiple transport and port operators in a regional port. Preliminary results show promise for the identification and delivery of an agreed approach minimizing port congestion and supporting value chain resilience.

2 Logistics and Supply Chain Integration in Ports: The Role of Technology

Conventional responses to terminal congestion have tended to take an inward focused perspective on port terminal operations or focus on the potential benefits terminal and carriers can achieve through collaboration and integration. Some studies have adopted a similar view of the port's land-side users and the supply chains they operate in or examined how information systems may be used to balance competing user needs. The role of ports in supply chains has increased in importance in the last decade, as it has become recognised in the research literature that it should be an integral measure of port competitiveness(Robinson 2002). However, on the ground, most practical integration and collaboration efforts remain limited to terminals or ports and shipping lines and are, to a large extent, a result of the continuous drive of shipping lines to reduce operating costs (De Martino and Morvillo 2008). In response to the challenge of growing congestion at ports and in particular regional ports, two main approaches have been adopted – (i) Port and traffic modelling approaches, (ii) empirical evaluations of systems' effectiveness. While modelling approaches indicate efficiencies may be achieved to mitigate port congestion (Chen et al. 2013; Chen and Yang 2010), empirical studies show that contemporary approaches fail to deliver the anticipated efficiencies (Bentolila et al. 2016; Giuliano and O'Brien 2007). For example, terminal appointment systems (TAS) are the most cited solution to manage congestion. These tend to be implemented with limited consideration of the key factors within hinterland supply chains and port users' requirements. This stated, given that these TAS are usually technology based tools, there are opportunities to incorporate changes to the rules 'engine' that would more readily accommodate these external user requirements in ways that may more positively impact on overall congestion management (Morais and Lord 2006).

As a result of changing customer requirements and shipping lines' drive to improve operational efficiency, the need for ports to become integrated links into their supply chains has arisen (Ascencio et al. 2014; Robinson 2006). Several studies have used surveys to identify port integration measures. These found that information and communication technology, intermodal or multimodal integration, value added services and supply chain integration practices (Panayides et al. 2008; Tseng and Liao 2015), relationship with users (Tongzon et al. 2009) and organizational integration (Bichou and Gray 2004; Panayides and Song 2013) are the most relevant aspects to be considered to measure the integration of ports in the supply chains. The majority of respondents of the surveys were executives from port or terminal operators. It is therefore unclear therefore, if the views expressed by the respondents cover confirmed or perceived requirements or needs of the maritime transportation side, the hinterland transportation side or both. There are a number of benefits for integrated terminals and ports in supply chains. Tseng and Liao (2015) find that integrating with supply chain partners improves operational processes speed and enhance performance. Furthermore, as a result of integration, ports and terminals can improve their competitiveness and strengthen their services (Franc and Van der Horst 2010).

A different approach in identifying port integration is taken by Van Der Horst and De Langen (2008) who focus specifically on hinterland transport and particularly the mechanism to enhance land-transport coordination. Interviews with a broad range of port, hinterland and industrial stakeholders reveal that the main coordination mechanisms are (1) financial and non-financial incentives, (2) alliances, (3) change of scope and (4) collective action. Coordination of hinterland flows and anticipation of workload information is found to be essential element for the efficient use of equipment (Ascencio et al. 2014; Olesen et al. 2012). It is therefore evident that supply chain considerations have not extended to the port's hinterland. Similarly, when tackling the issue of gate congestion, a number of approaches have focused on the requirements of the terminals rather than their land-side users.

Terminal gate congestion is an issue that has plagued multiple locations, from regional ports to international gateways. There are multiple methods to manage and alleviate gate congestion investigated in the literature. These can be split into two main categories: capacity and operational management. The capacity of terminal gates are determined by the number of operating hours, the number of gates and the throughput associated with each gate (Maguire et al. 2010).

Gate capacity management can be done by extending the gate working hours (Bentolila et al. 2016; Giuliano and O'Brien 2007) which increases the time available for trucking companies to deliver goods. Gate automation technologies (Maguire et al. 2010; Stahlbock and Voß 2007) are alternatives that reduce the document processing time. Operational management can be assisted by terminal appointment systems or vehicle booking systems (Huynh et al. 2016; Morais and Lord 2006) and peak hour pricing or incentive programs (Giuliano and O'Brien 2007). Terminal appointment systems limit the number of trucks that can arrive during a certain time at the gate, depending on the available capacity at the terminal. Peak hour pricing provides economic incentives or disincentives for trucks to arrive at particular times.

In general, modelling approaches results indicate that the implementation congestion management systems can have a significant positive impact on both terminal and transport companies' equipment use. For example, Chen et al. (2013) found that truck waiting time averages decrease from 106 minutes to only 13 after the implementation of vessel dependent delivery time windows, while Chen and Yang (2010) find an average truck waiting time reduction from 106 to 9 minutes, after the implementation of a similar system. Other implementations of terminal appointment systems reveal smaller changes to the truck turnaround time, from 60 to 51 minutes (Zhang et al. 2013) or as much as 15% if arrivals are evenly distributed during the day (Sgouridis and Angelides 2002).

Modelling results show there is clear merit in implementing solutions to manage and evenly distribute traffic flows across the operating hours of the terminal gate. However, this implies that the port community supports the congestion management initiative and makes the best possible use of the systems implemented. Empirical analyses of effectiveness of congestion management systems start with one of the most heavily discussed examples is the one of the Los Angeles/Long Beach container port complex in California, United States (Giuliano and O'Brien 2007). A general observation that emerges from multiple studies is the lack of stakeholder engagement. For the LA/LB port complex, there was little allowance made for the business demands of the actual users of the terminal appointment system, the transport companies. This can explain, in part, why appointments were used in less than 30% of deliveries (Giuliano and O'Brien 2007). The lack of stakeholder engagement is evident also in the implementation of the off-peak program at the NY/NJ port complex where very small changes in traffic distribution were observed before and after the implementation of congestion pricing. The minimal difference, only US$ 1, between the peak and off-peak tariff had a limited impact on changing truck arrival patterns (Holguin-Veras et al. 2005). Furthermore, a common feature of terminals implementing gate congestion solutions is the port centric approach used in designing the congestion management systems. On area where this is evident are the opening times of terminal gates which operate 24 hours per day. By implementing congestion pricing or terminal appointment systems, terminals are forcing the port community to operate 24 hours per day (Davies 2013).

Information and communication technology (ICT) often facilitates the information flow between multiple actors in the port space. Automated gate systems have been enabled by technologies such as Optical Character Recognition (OCR) and Radio-Frequency Identification (RFID) that aim to reduce the manual processing time of truck information (Heilig and Voss 2015; Morais and Lord 2006) and improve transport security (Rizzo et al. 2011). RFID enables automatic collection and verification of truck details (Huynh et al. 2016) thus, further supporting a streamlined and efficient gate operation. RFID technologies are also used to enable electronic toll collection where road pricing measures are introduced. Another approach to alleviate gate congestion that relies heavily on information technology is the terminal appointment system. Some systems are web-based applications while others are integrated into terminal or yard management applications (Morais and Lord 2006). Ensuring the use of terminal appointment systems by trucking companies and their drivers has proven a difficult challenge in practice. One concern expressed by the terminal operators is that "truckers are sufficiently sophisticated to schedule time slots, and frequently end up missing appointments."(Morais and Lord 2006) suggesting that the user interface may pose some challenges for the drivers. Another point of concern is the apparent incompatibility between the system's rules and the trucking companies' business demands. The 'rules engine' has been criticised by land transport operators for being inflexible by not allowing changes to the booking or resetting the process and also for being vulnerable to manipulation by users who exploit the system (Huynh et al. 2016; Navis 2003).

The literature emphasizes the importance of port and terminal integration in supply chains for improving competitiveness. At the same time, current approaches are centered mainly on the port or terminal perspective, and often overlook the requirements of the land-side users. Therefore, the emerging research question of this study is:

How can an integrated information systems approach between terminal operators and land-side users improve supply chain value by alleviating terminal gate congestion?

Two resulting sub-questions are:

- What role can an integrated information system play in addressing terminal congestion involving multiple land-side users?
- How should any socio-economic and/or environmental impacts generated through the deployment of an integrated information system be identified and evaluated?

3 Methodology

The research philosophy that underpins this research is a mixed-method case study approach with an interpretivist epistemology. The research strategy is a three-stage baseline, intervention, and evaluation approach using multiple case studies to explore the impact of an integrated information systems approach on improving supply chain value by alleviating terminal gate congestion. The case study method is desirable as it can provide a more informed basis to generating theories (Eisenhardt 1989). Multiple case studies are desirable to overcome concerns over the uniqueness of the situation and the lack of generalizability of the findings. Including more case studies opens up the possibility of direct or theoretical replication and, due to differences in the cases' contexts, increases the generalizability of the findings (Yin 2003).

The focus of the four case studies planned are terminals involved in bulk primary produce supply chains. Focus on a single commodity is desirable in our case as it limits the number of intersecting supply chains and reduces the number of potential environmental factors affecting the supply chains. Furthermore, some bulk terminals are focused on a single commodity which limits the impact other port users, either on the maritime or land side, have on the terminal's operations.

Each of the case studies is expected to be conducted over 9-12 months and will be conducted in phased approach that will take a total of 18 months. The baseline phase is planned to last 12 to 20 weeks and aims to gain a thorough understanding of the stakeholders' supply chains and perform an audit and assessment of exiting information systems. Furthermore, this phase highlights if improving information flows among supply chain partners can improve stakeholders' value. To achieve this aim, multiple data collection techniques are used:

a) Semi-structured interviews with 10 to 15 key stakeholder personnel. Roles such as business development, land and/or maritime operations, IT and database management are of interest. These roles may be clearly defined in larger companies such as the port. However, in smaller companies, they are often performed by one or two persons. Given that some companies in the supply chain under our scope are relatively small, the number of participants is deemed sufficient to extract the most valuable and relevant information for our research. The interview stage is also a critical opportunity to engage stakeholders in the congestion issue and improve their receptiveness to alternatives proposed in order to overcome the lack of stakeholder engagement issue identified in the congestion management literature;

b) Stakeholders' annual reports, industry publications and agency statistics assist in generating the macroeconomic picture in which enterprises operate;

c) Site visits at the terminal operations, the processing facility and at the production sites provide a first-hand experience to the operational issues the companies are facing on a daily basis;

d) Individual truck trip data regarding total trip duration, truck processing times and waiting times are collected from transport companies using third party fleet management software and GPS tracking hardware installed on the trucks. These data are complemented by total turn-around times generated by weigh-bridge visits before and after unloading and serve as input for the next phases of the study;

The data collected is analysed from multiple perspectives. The semi-structured interviews, documents, industry reports and site visits are used to generate a comprehensive map of the supply chains that intersect at the terminal gate and the bottlenecks in the system. Observations from site visits regarding operational steps and time taken for each stage are used in a simulation model of the terminal.

The simulation model's inputs are the number of trucks, trailers, and unloading bays, the equipment maximum payload and the time taken for each stage of the unloading process. The stages are: weighing-in, driving to the unloading ramp, unloading, driving to weigh-bridge, weighing-out. The number of trucks and trailers and their initial arrival times are drawn from data collected from GPS tracking hardware and the weigh-bridge facility. The model outputs the average expected hourly facility throughput, number of trucks serviced, service time per truck and queuing time for each stage. These outputs are compared to the real situation for validation with the real-life situation. The simulation is then used to evaluate the effectiveness of various changes in the system such as variations in unloading times, changes in truck arrival distribution or eliminating stages from the unloading process. This analytical stage provides the basis for evaluation of alternatives most appropriate for implementation at each of the focal terminals in our case studies.

The intervention stage is expected to last between 12 and 20 weeks. It is anticipated that the implementation of a terminal appointment system (TAS) will be the information systems approach utilized to manage the incoming flow of trucks to the terminal gate. The solution may be either an off-the-shelf purchase or an in-house design that integrates with existing terminal operating systems. To complement the implementation of the TAS, workshops with stakeholders are held to inform, engage and seek feedback from the direct and indirect users of the terminal's facilities.

Finally, the evaluation stage is anticipated to last between 6 and 10 weeks. The evaluation is both quantitative and qualitative in nature. It aims to answer the second research question regarding the socio-economic and environmental impact following the implementation of the TAS. The qualitative evaluation is a series of semi-structured interviews with key stakeholders' logistics or export management personnel. The aim is to identify whether their perception of the situation at the terminal has changed following the implementation of the congestion management solution. The quantitative evaluation is a statistical comparison between data collected during the baseline phase and new data collected following the implementation of the congestion management solution. The literature evaluates performance changes from the cost (Huynh 2009), time (Chen et al. 2013) and environmental perspective (Morais and Lord 2006). The truck turn-around times collected using the truck monitoring software and weigh-bridge information are compared with new data collected. Improvements in idling time have a direct environmental impact as idling engines generate green-house gases emissions while in operation. Furthermore, improvements in truck turn-around time are a measure of socio-economic impact. This impact translates to increased equipment productivity that allows terminals and transport companies to handle additional throughput with existing equipment and generates cost savings for forestry companies.

4 Case study progress and preliminary findings

The current research is progressing case 1 at a terminal in a regional Australian port. Progress to-date is discussed in this section. The focus port of this case handles a mix of containerized and bulk cargo together with a small number of passenger traffic for leisure on multi-purpose berths. The terminal operates as a bulk export facility for wood chips. Wood chips are a multiple-use processed wood product which is mainly used as an input for pulp production. It can also be used as raw material for engineered wood products or in the bio-based industry as fuel.

The wood chip for pulp production market is commoditized, competitive and highly price sensitive. It is also a cyclical industry which suffers downturns every 10 to 15 years (Macintosh 2013). Currently, the market is experiencing increased demand, mainly coming from China, but also increased competition with Brazil more than doubling their wood chip production over the last 15 years (New Forests 2017). In the next 40 years however, Australian production of wood chips is expected to drop by as much as 30% (ABARES 2016).

Three main customers, forest owners, operate three supply chains to export two types of wood chips from the terminal facility. The two wood chip products require separate storage and cannot be mixed. The throughput during this period has increased by almost 50% on a yearly basis over the last five years. Port vessel traffic may affect the vessel loading schedule at the terminal, as vessels are given berth space according to a strict set of priorities, however this has limited impact on land-side product deliveries. Trucks that deliver wood chips at the terminal interact with other trucks delivering cargo to other port terminals only at the weighing facility prior to unloading.

All wood chips are delivered to the terminal for export by truck leading to approximately 30.000 truck deliveries on a yearly basis. The terminal has been constantly improving land-side, storage and vessel loading infrastructure and has successfully coped with the increase in throughput so far. However, congestion at the terminal gate or the public weigh-bridge, a mandatory stopover prior and after unloading, occurs frequently. Furthermore, cases where trucks queue for more than an hour to unload their cargo are no longer isolated occurrences. The prospect of increased throughput coupled with an evident need to address land-side congestion have prompted the terminal operator to seek potential congestion management solutions.

Preliminary findings resulting from the interviews carried out in the first stage of the research to gain an in depth understanding of the stakeholders' supply chains indicate that:

a) Deliveries at the terminal typically scheduled by contractors handling the transport task. Information on other deliveries, current terminal workload or issues is unavailable between stakeholders.

b) The truck weighing process is a crucial stage in the supply chain as it triggers the reconciliation of contractual arrangements between the forest owner, wood chip mill, transport company and the terminal operator. The technology used for this stage can be extended to improve real-time visibility on of the transportation task.

c) The supply chains delivering goods at the terminal are relatively inflexible to unexpected events such as equipment break-downs or temporary closures.

Three main customers, forest owners, use the terminal to export wood products. Two companies operate similar fragmented supply chains. One difference between the two is that one can produce two types of product while the other can only produce one. Forest harvesting and log haulage operations to the processing mills are subcontracted to multiple small and medium sized specialized companies. The harvest and haulage companies deliver the round logs to a contract wood chipping mill that processes the logs and stores the resulting wood chips until available storage space at the terminal becomes available. Terminal space is limited as there are two types of product that can be delivered but only one storage facility is contracted quay-side. This means a relatively short window of time in which deliveries can be made is available. Deliveries are dependent on the vessel arrival schedule and the industrial customer's requirements. The contact with industrial customers takes place via a broker that collectively markets products from multiple forest owners on the international market.

The third forest owner runs a more integrated operation. The timber harvest and haulage operations are subcontracted. The round logs are delivered to owner's own wood chipping mill. The company only harvests one type of product. The wood chips are delivered quay-side using a transport company contracted specifically for port delivery using dedicated assets. There are physical limitations to the amount of product that can be stored on quay, however deliveries can take place on a continuous basis as opposed to the previous case. Furthermore, contact with industrial customer is handled internally.

There are multiple information systems supporting the different supply chains. An important observation is that there is a disjoint between systems tracking the logs, by weight or volume, through the various stages of harvesting and haulage and the systems further downstream related to wood chips. This is potentially related to the fact that wood chips are produced and stores in bulk and the same level of precision seen in log management is not required. At the same time, wood chip production is naturally dependent on the volume of round logs brought in as raw materials. Two companies transport woodchips from the mill to the port. One of the transport companies is integrated with the contract wood chip mill. Therefore, deliveries are centrally decided by the mill itself. The transportation distance from the mill to the terminal is under 10 kilometres and, so far, the company has not implemented any tracking technology for their trucks. An important observation in this case is that the scheduling stage of the delivery process is done in isolation with other terminal users. This means that conflicting arrival times of trucks may occur and that the supply chains are inflexible to unexpected downstream events.

Both transportation companies make use of RFID swipe cards to support their terminal deliveries. The delivery process is split in three stages. The first stage involves weighing the truck using the port's weigh-bridge. The weigh-bridge is public and used by multiple transport companies. Drivers swipe the RFID card on the reader which encodes information on the forest owner, transport company and wood product type. The second stage is the truck unloading. This is performed using a hydraulic dumper that empties on a conveyor belt system. Conveyors deliver wood chips to the appropriate stockpile. The third stage is returning the empty vehicle to the port's weigh-bridge to be weighed empty. The driver scans the RFID card on the weigh-bridge reader which registers the tare weight of the truck. A receipt containing the net weight of the payload and other RFID information together with the time between the two weigh-bridge visits is printed. This three-stage process is repeated for every truck delivery made at the terminal. The weigh-bridge visit information is essential in the process to settling and reconciling contractual arrangements between the forest owner, wood chip mill, transport company and the terminal operator. This RFID technology used in this process may be extended and integrated with the congestion management solution to provide real-time information to terminal users.

5 Conclusion

Port terminal gate congestion leads to significant economic losses for transport operators and greenhouse gasses emissions. An important reason why this problem occurs is the narrow, internal perspective stakeholders take when tackling this issue. This is evident both in the literature for port integration in supply chains and in congestion management approaches. Theoretical solutions have illustrated significant potential efficiencies and cost savings that can be achieved however, practical implementations have struggled to achieve significant results. Partial failure of congestion management systems is due to low solution acceptance by the trucking industry. Reasons for that are inflexible systems to transporters' business demands, lack of engagement from the port or terminal operators, and one-sided benefits derived by the terminal from the congestion management systems.

Progress to date is illustrated with the case study of a wood chip export terminal in regional Australian port that receives high frequency deliveries of two timber products from a small number of customers. Preliminary findings indicate that the delivery schedule at the terminal does not account for other companies' planned arrivals, as this information is unavailable for stakeholders. The truck weighing process is a crucial stage in the supply chain as it triggers the reconciliation of contractual arrangements between the main stakeholders. The technology used during this stage can be extended to be used in the terminal appointment system proposed. The supply chains delivering goods at the terminal are relatively inflexible to unexpected events such as equipment break-downs or temporary closures. A terminal appointment system is expected to be implemented to alleviate terminal congestion and improve supply chain value and resilience. The terminal does not bear the economic cost of congestion to the same extent as other actors in the supply chain. However, by taking an integrated perspective over the supply chain, it can assist in unlocking supply chain value throughout multiple supply chains through better coordination of the intersection points.

6 Limitations and further research

The case study research approach generates in depth understanding of the companies under the scope and the environment they operate in. This method is not without limitations. The most notable limitation is lack of generalizability of single case study findings. Findings from one study site may not apply to another as internal and external circumstances vary. For this reason, we aim to include multiple sites where we can perform both direct replication and theoretical replication to enhance the generalizability of the study.

Moreover, a substantial part of the terminal appointment literature is based on applications in container terminals which feature both import and export flows. Many primary produce supply chains feature only one flow, either import or export. This provides an opportunity to view each stage in the supply chain more clearly. However, a limitation is that there is no certainty that findings from the more simplistic bulk produce supply chain can be extended to more complex chains featuring both import and export flows.

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