The effects of a more accurate ETA and real time sharing of the berth window on operations in a container terminal
A simulation study into information exchange in the container transport chain

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Abstract: The globalisation of world trade led to a significant growth in containerized maritime transport. This puts pressure on container terminals to improve their operations. Transport container chain literature proposes improvement of the accuracy of the estimated time of arrival (ETA) and real time sharing of the berth window as ways to improve the performance and productivity of container terminals. The quantitative effects of this improved information exchange on the productivity and performance of a container terminal is unknown. In this study the effect of a more accurate ETA and real time sharing of the berth window are thoroughly estimated using a simulation model. It shows that both improving the accuracy of the ETA as real time sharing of the berth window improves the gang productivity, but that the effect on ship turnaround time is limited.

Keywords: Estimated time of arrival, Berth window sharing, information exchange, Container transport chain, Container terminal

1. Introduction
The globalisation of world trade led to a significant growth in containerized maritime transport. Nowadays more than 90% of the international transport is moved by ships and most is packaged in containers (Fransoo & Lee, 2013, p253). This increased traffic combined with bigger ships and bigger call sizes put container terminal under pressure (Nguyen & Notteboom, 2018, p1).

Carrier are pressing terminal operators to reduce their handling times and handling rates in order to reduce the transport costs of a container further. One way of improving the productivity and performance within the container transport chain is by improving the information exchange between transport partners. Transport container chain literature proposes improving the accuracy of the estimated time of arrival (ETA) and real time sharing of the berth window to improve productivity and performance of container terminals. It is unknown what the quantified effect of these two information exchange alternatives actually is. Deepening the understanding of this knowledge gap is the main objective of this scientific paper. The main research question is:

What is the effect of improving the accuracy of the ETA and real-time sharing the berth window on the performance and productivity of container terminals?

In section 2 previous work about the information exchange in the container transport chain is discussed. Section 3 present the case of the port of Algeciras, the terminal model and ship arrival generator. Section 4 describes the modelling of the information exchange alternatives. The executed experiments and results are presented in section 5. Section 6 contains the discussion. The conclusion can be found in section 7. Suggestions for further research are presented in section 8.

2. Previous work
In supply chains information exchange has a positive effect on both the service level as the total costs (Li & Lin, 2006, p1642). Much literature is available on the information exchange in the supply chain context. Improving information exchange can be achieved by improving information sharing or by improving the quality of information that is being shared (Li
Information quality consists of the accuracy, adequacy, credibility and timeliness of the information that is being exchanged (Monczka, Petersen, Handfield, & Ragatz, 1998, p559). Compared to supply chain literature, literature on information exchange in the container transport chain is still limited (Gharehgozli, Roy, & De Koster, 2016, p139).

Operational research in the container transport chain often assume an ETA that is exact the actual time of arrival (ATA). A clear example is research on the berth allocation problem and the quay crane assignment problem. Most research either assumes static or dynamic arrival times (Bierwirth & Meisel, 2015, p620). When assuming a static arrival time, all ships are already in the port when the berthing schedule is made (Imai, Nishimura, & Papadimitriou, 2001, p404). With a dynamic arrival time ships have different arrival times. It is explicitly assumed that these arrival times are known when the berth schedule is created (Imai, Nishimura, & Papadimitriou, 2001, p406).

There is discussion in literature whether the estimated time of arrival (ETA) really is accurate as assumed. Lind et al (2015, p501) states that ETA is often corresponds with the ATA. Other claim that there are discrepancies between the ETA and ATA and that hurts the productivity and performance in the terminal (Fancello et al., 2011, p. 2; Xu, Chen, & Quan, 2012, p. 123). Improvements of the accuracy of the ETA up to 25% have been reported (Parolas, 2016, 69, figure 21).

One of the two information exchange alternatives researched in this paper is increasing the accuracy of the ETA. Two mechanisms on how an ETA affects the performance and productivity of a container terminal are discussed. The first is the allocation of workforce. Based on the ETA of inbound ships a workforce planning is made. Discrepancies between the estimated time of arrival and actual time of arrival lead to overmanning and undermaning in the terminal, decreasing productivity and performance (Fancello et al., 2011,p2). The second mechanism discussed in literature is the allocation of the berth and ship to shore cranes based on the ETA. An inaccurate ETA cause the need for the terminal operator to continuously reschedule the allocation of cranes, resulting in poorer performance compared to the baseline crane assignment plan (Xu, Chen, & Quan, 2012, p125).

The second information exchange alternative researched is real time sharing of the berth window. Sharing of the berth window enables a carrier to adapt its speed based on the predicted state of the terminal at arrival. This can decrease waiting time and increase the utilization of terminals resources (Lang & Veenstra, 2010). The study of Lang & Veenstra (2010) has some limitations. The performance of their container terminal is deterministic, the availability of equipment is constant and they assume that the ETA is known and accurate. In this paper the a more extensive model of a container terminal will be used and perfect information on the ETA is not assumed. This will introduce more uncertainty regarding the nomination of workforce and allocation of cranes in the container terminal.

3. Case: Port of Algeciras

In this research we focus on a transhipment terminal in Algeciras. Algeciras is one the biggest transhipment ports in Europe. It is called by both mega vessels on the Asian – Europe trade lane as smaller feeder vessels calling ports on the Mediterranean and the west African coast. In the considered terminal 14 STS cranes can work concurrently. A quay of around 2300 meters is available. Based on the berthing window of the transhipment terminal it is assumed that 6 ships can berth simultaneously.

3.1 Quality of the data

This research is based on two datasets. The first is a pro forma berth window of a real terminal in Algeciras containing 7 days of ship arrival data in the terminal. Based on this data the ship arrival generator is build.

The second data set is contains around 40 vessels calling the port of Algeciras during a 10 days period with the ATA and their communicated ETAs. The dataset contains the metadata of the estimated time of arrivals. The moment that the estimation was made and its source were recorded. The recorded sources were the Port Management System (PMS), the information system of the terminal (Comms) and Marinetraffic. The dataset is considered of high
quality due to the usefulness of the metadata. However the dataset contains a systematic measurement error. The affected data points where identified and corrected using a cluster algorithm. The inaccuracy of the ETAs in the cleaned dataset is lower than in the uncleaned dataset. This means that when the hypothesis that these datapoints where measured wrongly is false, improving the accuracy of the ETA and real time sharing of the berth window has more effect on the productivity and performance of the terminal than reported in this paper.

This research is supported by terminal experts from Navis and terminal simulation experts from Macomi. Terminal experts with local knowledge on the Port of Algeciras were consulted to assess data quality and local gang nomination mechanisms.

3.2 Terminal model
The terminal model consist of a quay and a yard which are coupled to each other. The quay consists of identical STS cranes. A STS crane has a productivity of 30 moves per hour. The execution time of a move is drawn from a normal distribution. The cranes are capable of doing twin moves for 20 feet containers. The terminal is open 24 hours a day.

The performance of the STS cranes is constrained by the performance of the yard. The performance of the yard is based upon the number of RTG’s active in yard and the yard occupancy. Peaks in the yard occupancy constrain the performance of the quay, introducing more uncertainty in the allocation of berths and equipment to vessels.

The model is a discrete event simulation model. It is implemented in Simio version 10.

3.3 Arrival of ships generator
Based on the berth window of a real terminal in Algeciras a ship arrival generator is developed. Ships enter the model when there are 26 hours outbound of the terminal. The goal of the generator is to generate the ships entering at this starting point based on the pro forma berthing window. The pro forma berthing window is formed by negotiations between the carrier and the terminal operator and thus controlled. Most simulation studies in literature use a generator based on a Poisson distribution to represent the randomness of the arrival of ships in the terminal. In this paper ships are generated using a normal distribution with the equidistance approach as mean (Polman, Asperen, Dekker, & Arons, 2003). The initial speed of the ships is 18.5 knots. Randomness of arrival at the terminal is reinforced by random delays that ships face when sailing towards the terminal. This is discussed in section 4.

Four classes of ships are distinguished based on the number of moves they will cause at the terminal. Each ship has a service level agreement (SLA). It contains the number of discussed cranes
in the terminal. Ships also have a maximum number of cranes that can operate the ship. Both properties are dependent on the class of the ship.

4. Modelling of information
The main goal of the model is to research the effect of improving the accuracy of the estimated time of arrival and real-time sharing of the berthing window on the performance and productivity of the container terminal.

4.1 Modelling the inaccuracy of the ETA
In Figure 1 the discrepancies between the estimated time of arrival and the actual time arrival are shown. Three paths of successive ETAs of three vessels are depicted to visualize how the accuracy of the ETA can change over time. It can be seen that the ETA is not exact the ATA. Most estimations have a deviation between 5 and minus 5 hours, but also bigger deviations are present. There are more data points with a positive deviation than a negative one. It can be concluded that there is some inaccuracy in the ETA and that the ETA tends to underestimate the time of arrival.

The inaccuracy of information is incorporated in the simulation model using a biased random walk combined with a binomial distribution as shown in (1). The biased random walks is executed every hour for every ships that is on its way towards the terminal. Figure 2 shows possible paths on the discrepancy between the ETA and the ATA based on the biased random walk.

\[ y_t = y_{t-1} + B(1, 0.5) \ast N(0.1, 0.75) \]  \hspace{1cm} (1)

4.2 Nomination of gangs
The ETA is important for the allocation of workforce. In the case of Algeciras, stevedoring gangs need to be hired from the local stevedoring company. Every day at noon, the gangs for the next four shifts need to be nominated. These four shifts are each six hours. They span from 14:00 that day till 14:00 next day. The time that the ships will be serviced at the terminal is estimated based on:

- The estimated time of arrival
- The number of cranes in the service level agreement (SLA) of the ship
- The number of moves of the ship at the terminal
- The average moves per hour of the STS cranes in the previous 24 hours

Gangs will be reserved for the ships during the shifts that it will be serviced. When the ship only will be serviced during a part of the shift, the gang is nominated for the whole shift. The number of gangs nominated per shift is equal to the number of STS cranes in the SLA. There is a maximum number of gangs that can be nominated. In this case it is 14.

4.3 Ship to shore crane allocation
The ETA is important in the allocation of STS cranes to ships. Two algorithms are developed that allocate cranes based on the estimated time of arrival. The first algorithm is used when a ship arrives at the terminal. The main goal of the algorithm is to predict whether more cranes than discussed in the SLA can be assigned to the ship without violating the SLA of other inbound ships. The main assumptions of this algorithm are:

- The allocation of the cranes is time invariant. Once they are allocated they keep servicing the ship until it is finished.
- All cranes are equal and can operate all ships.
- The allocation of cranes is not constrained by their location on the quay.

The algorithm is used when a ship arrives at the terminal. A activity diagram of the algorithm is shown in Figure 5 (Appendix A). Upon arrival of the ship, the terminal operator will try to assign at least half of the cranes in the SLA to the ship. When less than half of the cranes are available,
the ship will be send to the waiting area. When more than half of the cranes are available, these cranes will be assigned to the ship and the ship will be allocated to a berth.

In case more STS crane are available upon arrival than discussed in the SLA, the terminal will assign additional cranes when this does not violate the SLA of inbound ships. This logic is implemented in an algorithm using a double loop. The first loop keeps track of the number of STS cranes that the terminal operator is trying to assign. The second loop keeps track of time within the algorithm. For every timestep it is checked of all the SLAs still can be fulfilled given the departure and arrival time of other ships and changes in the number of available gangs. When a SLA of an inbound ship is violated before servicing of the arrived ship is estimated to be completed, the algorithm will try again with one crane less. This will continue, until all SLAs can be fulfilled during the service time of the ship or until the number of cranes in the SLA is reached.

The second algorithm is executed every time that a new works shifts. This algorithm is similar to the algorithm shown in Figure 5. Due to overmanning in the terminal it can happen that some gangs will not be assigned to a ship during their shift. These gangs are reassigned. There are two additional assumptions:

- Gangs will be assigned to the ship with the earliest estimated time of departure given that there is at least four hours of work.
- The allocation of cranes is constrained by the location of the STS crane. The probability that a crane can service the ship is equal to the number of idle cranes divided by the total number of cranes. This reflects the inflexibility that a terminal operator has when it wants to reschedule cranes in between gang shifts.

4.4 Sharing of the berth window
The berthing window changes continuously caused by both uncertainty from the arrival of ships as uncertainty from the performance of the terminal. In the simulation model a new berthing window is generated every 15 minutes based on the current state of the terminal and the ETAs of the inbound ships. When this berthing window is shared with the carrier, it can increase or decrease its speed based on the predicted state of the terminal at its time of arrival. The main assumptions of the algorithm are:
- Ships will only reduce speed in order to avoid waiting times at the terminal.
- Ships will only increase speed when the number of cranes in the SLA and the berth is available earlier.

An activity diagram of the algorithm is shown in Figure 6 (Appendix A). The algorithm starts with the current states of the terminal and the estimated time of arrival of the inbound ships. The algorithms has own state variables that keep track of time and the number of resources at the terminal. Ships are sorted based on their ETA. The algorithm loops of this list of ships, starting with the ship with the earliest ETA. It determines it earliest possible ETA when it would increase its speed to 20 knots. A maximum speed of 20 knots is assumed as the effect of increasing the vessels speed on the bunker costs increases as the speed is higher. It is assumed that the carrier is not willing to sail faster than 20 knots. Based on the estimated states of the terminal the algorithm will decide if the ships will have to speed up, keep the same speed or reduce its speed when no resources will be available upon arrival. The vessels will not decrease their speed lower than 10 knots, because under 10 knots the effect of decreasing speed on the bunker costs is limited. The estimated time of arrival and estimated time of departure will be estimated. This process is repeated for all ships in the list.

5. Experimentation and results
The runtime of the experiments is set at 100 days. 21 of these 100 days are used as warm-up period to reach a steady state in the model, before the statistics are gathered. This warm-up period is needed as the model of the container terminal starts with an empty yard and berth which influence the results. Of each scenario 40 replications will be conducted.

The studied KPIs are the average terminal turnaround time of vessels, the waiting time of vessels and the average moves per hours of the STS cranes per gang. These KPIs will provide good insight in the performance and productivity
of the terminal. The input variables are the improvement of in the accuracy of the ETA, a Boolean whether the sharing of the berthing window is enabled and a number of ships that are operated in the terminal. The studied levels of the increase in ships serviced at the terminal are 0%, 5% and 10%. The results of the experiments are compared with the base case. The base case is the scenario where there are no improvements in information exchange. A full orthogonal design is chosen to test both for main effects as interaction effects.

Looking at the outcomes in Figure 3 multiple insights can be derived. The productivity of the gangs can be improved by increasing the accuracy of the ETA and by sharing the real berth window real time. Looking at the interaction effects in shows that combining both alternatives provides better results that the separate alternatives. Both measures influence the productivity of the terminal through the same mechanism: a better match between the workload and the number of resources at the terminal. The reason why sharing the berth window still improves the productivity of the terminal, even when the ETA is exact the ATA, is that it can spread the arrival of ships in favor of the terminal when too much ships are scheduled to arrive at the same time. The effect of sharing of the berth window on the productivity of the gangs decreases as the ETA become more accurate. This shows that an inaccurate ETA causes mismatches at the terminal and that less of these mismatches need to be repaired by sharing of the berth window when the ETA is more accurate. The effect of the information exchange alternatives decrease when the number of ships calling the terminal increases. When the number of ships calling the terminal increases, the terminal will be more like a queuing system where ships have to wait before they can be serviced. In these system, information about the future workload is less valuable.

Using ANOVA with Tukey honest significance difference test, the statistical significance of the results is tested (Keppel & Wickens, 2004, p5). A significance level of 0.05 is used. Figure 4 shows boxplot regarding the average of the used KPIs and the number of gangs nominated. Real time sharing of the berth window improves the productivity of the gangs statistically significant. Only an improvement in accuracy of the ETA of 50% or more improves the productivity.
Looking at the significance of the effect of information exchange on the ship turnaround time, it can be concluded that differences are not significant. The improvement in turnaround time is only statistically significant when both the berth window is shared as the accuracy of the ETA is exact the ATA. Sharing of the berth window result in statistically significant less waiting time at the terminal. There is no statistical significant difference in waiting times with different levels of accuracy of the ETA. The mean of the gangs nominated decrease as the berth window is shared or the ETA is more accurate. The difference becomes statistical significant when the berth window is shared with an improved accuracy of the ETA with 50% or more, or when the ETA is exact the ATA without sharing the berth window.

6. Limitations
No other simulation study of a container terminal could be found that dynamically nominates gangs based on the ETA. This dynamic nomination is an important feature of the used model and needed to study the effect of improving the accuracy of the ETA. It has one important limitation. When the productivity of the gangs increase, less gangs are nominated. This limits the effect of sharing the berth window on decreasing the ship turnaround time. It is expected that the improvement in gang productivity also can be translated to a statistically significant lower ship turnaround time when the number of gangs nominated would be kept constant across the different experiments.

This study assumes that allocation of the STS cranes to the ships is time invariant. A constant number of ships is assigned that keeps servicing the ships until it will depart. This is a simplification with regard to reality where it is very common that the number of cranes servicing the vessel changes. This provides more flexibility for the terminal operator to allocate its resources.

1 Letters are used to visualise the statistical significance of the results. Boxplot with the same letter are statistically speaking not different. Boxplots with different letters have a difference in their mean that is statistically significant. Multiple letters can be assigned to one boxplot.
The assumption that is not possible in the terminal, could increase the importance of the ETA in the model. If this is the case, the effect of improving the accuracy of the ETA and sharing of the berth window is less than reported in this study.

7. Discussion
Operations research regarding the container transport often assumes the accuracy of the ETA to be exact the ATA. This study shows that this assumption does not hold. The results show that an inaccurate ETA decrease the productivity of the gangs. It support the hypothesis by Fancello et al (2011) that increasing the accuracy of the ETA lead to less under and overmanning in the terminal, improving the productivity of the gangs. This way less gangs are needed for the same work inside the terminal. The maximum improvement of the accuracy of the ETA reported in literature is 25% by Parolas (2016). This study shows that the effect of this improvement on both the turnaround time as the gang productivity is limited. This shows that this information exchange alternative is mainly constrained by its technical feasibility.

The results of this study extends the findings by Lang & Veenstra (2010). Both studies show that sharing of the berth window has benefits for both the terminal operator as the carrier. Where Lang & Veenstra (2010) focus on a cost function, mainly from the perspective of the carrier, this research takes operational processes in the terminal into account. In addition to Lang & Veenstra (2010) this study shows that the effect of sharing the berth window decreases as the accuracy of the ETA increases. It shows that when the ETA is more accurate, less mismatches between the workload and the available resources at the terminal are present, which can be corrected by sharing of the berth window. In contrary to a significant improvement in the accuracy of the ETA, sharing of the berth window is technical feasible. It is mainly blocked by a lack of willingness from the terminal operator and carrier to share information. This study contributes to this discussion by showing that sharing of the berth window has benefits for both the terminal operator as the carrier.

Compared to literature about information exchange in the supply chain, literature about the exchange of information in the container transport chain is still limited. This research show that information exchange in the container transport is an interesting field of research with much potential to improve the transport chain. More research on this topic should be conducted.

8. Conclusion
The goal of this scientific paper is to study the effects of an improved accuracy of the ETA and real time sharing of the berth window on the performance and productivity of the terminal.

Improving the ETA and sharing of the berth window both have a positive effect on the productivity of the gangs in a terminal. Both alternatives can be used next to each other, but the effectivity of sharing the berthing window decreases as the ETA becomes more accurate. This is explained by the fact that sharing of the berth window partly corrects the inaccuracy of the ETA. The effect of both information exchange alternatives decrease when the number of ships calling the terminal increases.

Sharing of the berthing window does decrease the waiting times of ships, but the decrease in turnaround time is not statistical significant. This is explained by the outcome that the terminal nominates less gangs as it productivity increases, having less moments of overmanning in the terminal. This means that the gain in productivity of the gangs can be converted to a lower turnaround time for ships. Improving the accuracy of the ETA does not decrease the waiting time nor the ship turnaround time.

9. Future Research
Based on this research three topics for further research have been defined. The first topic is researching how the accuracy of the ETA can be improved more than the 25% that is currently achieved in literature. The results of this study show that the effect of improving the ETA with 25% is limited, especially compared to the effect of sharing the berth window. The second is extending the simulation model with a cost optimization algorithm. The adaption of speed needs to be based on minimization of a general
cost function that includes both the costs from the terminal operator as the carrier. The third topic is to research incentive schemes enabling implementation of sharing the berth window. Implementing information exchange alternatives is often blocked by a good incentive scheme for the participants. This research show that both the carrier as the terminal operator can benefit from sharing of the berth window. A good incentive scheme would support the actual implementation of sharing of the berth window.
References


Appendix A

1. Determine number of available STS Cranes in terminal
2. Reserve cranes for ships in waiting area
3. Less 50% of the cranes in SLA ship are available → Send ship to waiting area
4. Decide number (Q) that can maximally assigned to the ship
5. Q ≤ cranes in SLA → Assign Q to ship
6. Q > cranes in SLA → Calculate ETC based on Q
7. Process changes in crane allocation in timestep
8. Less than 0 cranes available
9. 0 or more STS Cranes available
10. Change occurs due to departure of ships, arrival of ships and changes in the available gangs
11. Set Q = Q - 1
12. Reset Time (T)
13. Set T = T + timestep
14. T < ETC
15. T => ETC

Figure 5 - Algorithm allocation of STS cranes upon arrival
Figure 6 - Algorithm: Sharing of the berth window