LOGISTIC CONTROL OF MODERN DRY BULK TERMINALS

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SUMMARY

This paper discusses the logistic control of modern dry bulk terminals. It starts with a general approach towards terminal modelling. It further discusses detailed terminal design and logistic control issues. To illustrate these issues, the performance of three typical dry bulk terminals is discussed. The import side of these terminals is different, they all export bulk solid material using vessels.

1. INTRODUCTION

Dry bulk terminals are used worldwide as a buffer between an incoming flow and an outgoing flow of bulk solid materials, referred to in this paper as respectively the import flow and the export flow.

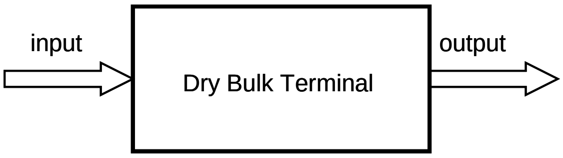

Figure 1: A black box approach towards the dry bulk terminal as a system

In order to enable a proper analysis of the logistic control of dry bulk terminals, the terminal as a system is modelled as a black box following the Delft systems approach [1]. In Figure 1 this approach is depicted schematically. In the bulk terminal system input and output such as orders, products, and resources go in and handled orders, delivered products, and used resources go out. In this paper only the product flow is considered, hence the single arrow at the input and output side of the black box.

If one zooms into the black box then in the dry bulk terminal two layers can be distinguished: the operation system layer and the control system layer, (Figure 2). This model is called the proper model [1]. The control system layer monitors the results of the operation system and adjusts the operation if the results deviate from the expected results or standards. The control system layer communicates with the environment that expects a certain performance from the total system and that provide the requirements to the system to meet the expectations.

If the black box operational system is opened further then three sub-systems can be distinguished: the import system, the internal terminal system and the export system, (Figure 3). The import system concerns transport modes arriving at the terminal and/or supplying material to the terminal and the import interface to the terminal. The internal terminal system concerns the acceptance of material in the internal terminal process at the import interface, the process of handling, stacking, storage, reclaiming and/or supply of material at the export interface. The export system concerns the export interface to the terminal and the process of transport modes arriving at the terminal and/or the supply of material to the export process. As in the model shown in Figure 3, each sub-system has it own physical control system. In other words, the quay cranes have their own control system, the equipment used in the internal terminal system have their own control system, and the ship loaders of the export system have their own controller. On top of that, each physical control system is controlled by the overall logistic control system of the terminal. In this paper, two aspects of the logistic control are discussed in particular; the controllability of the import flow and the maintenance control.

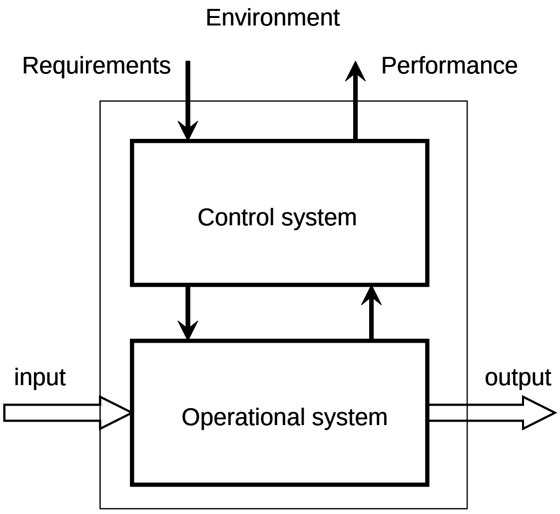

Figure 2: Proper model of a dry bulk terminal

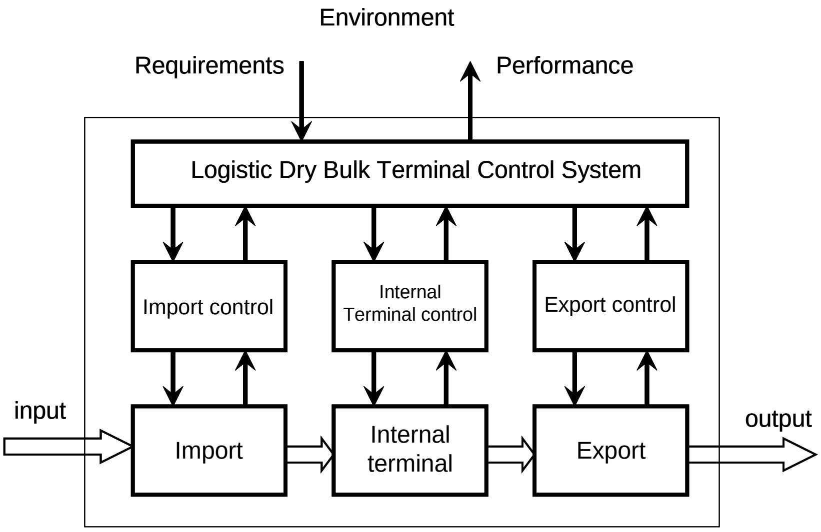

Figure 3: Proper model of a dry bulk terminal with sub systems

The transport modes available both on the import side as well as the export side are discontinuous transport systems, like vessels (all sizes), trains and trucks, and continuous transport systems, like belt conveyors. To analyse all possible combinations between import transport systems and export transport systems is beyond the scope of this paper. In this paper three examples of dry bulk terminals will be presented with different transport modes used for the import flow. These three examples are:

- **Railway system**: On the import side of the terminal bulk solid material is supplied by trains. The import interface is a train load-out station, here a tippler system. On the export side of the terminal a marine system utilising vessels is used. The export interface therefore consists of ship loaders.
- **Belt conveyor system:** On the import side of the terminal bulk solid material is supplied by a belt conveyor. The import interface is a transfer point used to discharge the belt conveyor onto a yard conveyor of the internal terminal system. On the export side of the terminal a marine system utilising vessels is used. The export interface therefore consists of ship loaders.
- **Marine system:** On the import side of the terminal bulk solid material is supplied by a marine system utilizing vessels. The import interface consists of ship unloaders. On the export side of the terminal there is also a marine system utilizing vessels are used. The export interface therefore consists of ship loaders.

These three systems are used to investigate the effect of the logistic control on the performance of a dry bulk terminal.

2. TERMINAL DESIGN

When designing a new dry bulk terminal, further referred to as bulk terminal in this paper, a number of conceptual design issues come up.

The first design issue is the determination of the *actual terminal size*, either in terms of m^2, in tons of material stored, or in percentage of the annual throughput. The size of the terminal depends, among other things, on the question of whether the export flow needs to be decoupled from the import flow. The export and import flows are coupled if situations occur and a request for material on the export side is held up because that specific material is not available on the terminal at the time of request. The request is then put on hold until the material arrives in the import flow. The result of it is that, whatever transport mode is used to accommodate the export flow, it has to wait in a queue. In the case of the three examples mentioned in the introduction, this means that a queue of vessels will appear, (Figure 4). If the terminal size is large enough to ensure that all materials are available in sufficient quantities, regardless of the export requests, then the export flow is decoupled from the import flow and queues caused by insufficient material on the terminal do not exist. The terminal size also affects the import flow. If the available free storage area is not sufficient to offload a discontinuous transport unit, like a train or a vessel, then a queue will appear on the import side of the terminal. As far as the logistic control of the terminal is concerned, what matters is the question whether or not a queue of transport equipment on the import side is acceptable. If it is acceptable then it has to be determined what length can be accepted assuming that costs are associated with waiting time.

The second design issue is the analysis of the **import interface.** On the level of the black box approach shown in Figure 3, this analysis starts by determining an appropriate offloading capacity, assuming a discontinuous transport mode, and the number of offloading positions. The actual number of pieces of equipment per offloading position is not relevant in the initial design stage. The number of offloading positions together with the offloading capacity determine the offloading position occupancy. The offloading position occupancy indicates the percentage of time an offloading station is occupied by an import transport unit. The analysis presented in Section 6 will show the relation between the offloading position occupancy and the queue of waiting transport units. In general two types of waiting time can be distinguished. The first is due to the unavailability of offloading positions. This may also be caused by malfunctioning of the offloading equipment. The second, mentioned before, is due to insufficient free storage area on the terminal. Once an appropriate number of offloading positions, as well as their offloading capacity, has been determined, the actual number of offloading equipment units can be determined. It should be noted that in practice the actual offloading capacity (throughput as a function of total available time) is less then half the design capacity of the offloading equipment. In case of a continuous transport mode the internal transport capacity has to match at least the capacity of the import interface.

Figure 4: Vessels waiting offshore to be loaded with bulk solid material

The third design issue is the analysis of the **export interface.** Similar to the import side, this is initially a matter of determining the number of loading positions and their loading capacity. After this analysis the actual number of the loading equipment can be determined. On the export side three types of waiting times can be distinguished. The first type is caused by the unavailability of bulk solid material, as mentioned before. The second type is caused by the unavailability of loading positions. The third type is caused by the inability of the internal terminal system to supply material due to the unavailability of equipment to supply material.

The fourth design issue is the analysis of the **internal terminal system**. During this analysis the storage capacity and position per material will be determined as well as the actual lay-out of the terminal in terms of equipment and redundancy, [2] and [3]. In particular, redundancy and reliability of equipment will be analysed in this phase.

3. LOGISTIC CONTROL

The previous section discussed four design issues and started to address some logistic control issues. Considering the three sub-systems mentioned in Figure 3, being the import, the internal terminal and the export, this section discusses the logistic control issues per sub-system.

IMPORT

On the import side the following questions affect the logistic control of the import side.

- **Who is controlling the import flow?** In general the import flow can be controlled either by the terminal (pull model) or the import supplier (push model). In the pull model it is also possible that the export clients define the pull request. Sometimes a terminal is owned by its customers. In that case it is assumed that the terminal defines the request for materials. For example, in case of a pull model the terminal can request the materials it needs from the import supplier(s). This enables a terminal to optimise the terminal size and the internal terminal processes. An example of such a terminal is the EECV terminal in Rotterdam harbour where the terminal can request material from Vale in Brazil in accordance to its need. In the case of a push model the terminal has no control over what material is supplied and when. This automatically means that the terminal grows in size. First of all because it needs to accommodate whatever material is supplied in whatever quantity. Secondly, if the export flow needs to be decoupled from the import flow then a sufficient safety stock needs to be stored on the terminal. An example of such a terminal is the Saldanha Bay iron ore export terminal where basically the Sishen mine determines what material it send to the harbour by train and when.

- **Is material coming in on a timetable type service or more at random?** If material comes in more or less on a timetable then obviously the import flow is much more predictable compared to if it comes in at random. The stochastics of the import flow then has a lesser impact on the performance of the terminal.
- **What is the variation in the arrival pattern of import transport equipment?** If it is assumed that import equipment arrives more or less in a regular pattern then the average time between arrivals of import transport equipment can be calculated. If the variation of arrival time exceeds the arrival interval then the offloading of import equipment will interfere with each other leading to queuing on the import side.
- **What is the variation in the offloading process of the import transport equipment?** This is related to the reliability and availability of the offloading equipment as well as the variation in import transport equipment type. For example, on a marine import terminal the vessel types can vary in size. Some vessels allow two cranes to offload a vessel simultaneously, whereas others allow three or only one.
- **What is the offloading position occupancy and how is that affected by the number and type of offloading equipment?** This is affected by the number of offloading equipment per offloading station. For example: if the offloading capacity required at a berth is 5,000 MTPH then either one 10,000 MTPH or two 5,000 MTPH grab cranes can be used, assuming an effective capacity of 50% of the design capacity.
- **Are the offloading positions specifically fit for one type of import transport equipment or more for general use?** If offloading positions are dedicated to a specific type of import transport equipment then that means that a queue can develop due to incompatibility of offloading stations and import transport equipment.

INTERNAL TERMINAL

On the internal terminal side the following questions affect the logistic control of the terminal.

- **What bulk solid material is put where and who decides that?** If the terminal can decide what material to put where then the storage area occupation can be optimised. For example, it makes a lot of sense to put material that forms a significant portion of the annual throughput in a position that has the shortest route to the loading stations. In addition, that material should be put in a position that has maximum accessibility in terms of redundancy in equipment.
- **How is the internal terminal system maintained?** Lodewijks[4] discussed maintenance strategies. The way a system is maintained has a significant impact on the performance of the system. Given a required minimum level of availability, the maintenance strategy determines the final number of equipment and the redundancy.
- **Does the system have a by-pass or not?** If the system has a by-pass then it is relatively easy to connect the import flow directly to the export flow. Whether that is possible or not depends on the controllability of the import and export flows - see the earlier discussion on the import side. In general, modern terminals today plan to by-pass about 20% of their annual throughput. This however seems to be rather optimistic.
- **Does the terminal have equipment that performs more than one function?** If a piece of equipment performs more than one function, for example a combined stacker/reclaimer, then in a case of malfunctioning the terminal loses two functions. Refer to Lodewijks [4] for a discussion on redundancy and combination of functions.
- **Does the terminal system have redundancy in terms of accessibility or not?** If a specific area of the storage area is accessible by more than one piece of equipment with the same function then it can be reached even if one of those pieces of equipment is malfunctioning. Again, referred to Lodewijks [4] for a further discussion on this issue.
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EXPORT

On the export side the following questions affect the logistic control of the export side.

- **Who is controlling the export flow?** In general, the export flow can be controlled either by the terminal (push model) or the export client (pull model). Most terminals operate according to the pull model. Another question is who decides which client gets served first in case only one loading position is available, either because of a limit in positions or because there is only one supply line available from the internal terminal, and more than one client shows up.
- **Is material going out on a timetable type service or more at random?** If material goes out more or less on a timetable then the export flow is much more predictable then if it goes out at random. The stochastics of the export flow then has a lesser impact on the performance of the terminal.
- **What is the variation in the arrival pattern of export transport equipment?** If it is assumed that export equipment arrives more or less in a regular pattern then the average time between arrivals of export transport equipment can be calculated. If the variation of arrival time exceeds the arrival interval then the loading of export equipment will interfere with each other leading to queues on the export side.
- **What is the variation in the offloading process of the export transport equipment?** This is related to the reliability and availability of the loading equipment as well as the variation in export transport equipment type. For example on a marine export terminal the vessel types can vary in size. Some vessels allow two cranes to load a vessel simultaneously, others allow for only one. The same holds for loading capacity; some vessels can be loaded at 3,000 MTPH others at 8,000 MTPH. Loading as well as offloading capacity is affected by the dewatering capacity of the vessels.
- **What is the loading position occupancy and how is that affected by the number and type of loading equipment?** This is affected by the number of loading equipment per loading station.
- **Are the loading positions specifically fit for one type of export transport equipment or more for general use?** If loading positions are dedicated to a specific type of export transport equipment then that means that a queue can develop due to incompatibility of loading stations and export transport equipment. For example, if a special loading position or berth is designed for barges then that can not be used by PanaMax vessels.

In the next three sections the three examples mentioned in Section 1 will be discussed. The purpose of showing these three examples is to show the effect of the logistic control and the transport mode used to handle the import flow on the performance of the bulk terminal. The focus will be in particular on the controllability of the import flow and the maintenance control.

4. RAILWAY SYSTEM

The first example mentioned in the introduction is a dry bulk terminal with a railway system on the import side. This implies that bulk solid materials are supplied to the terminal by trains, see example in Figures 5 and 6. The import interface is a train load-out station, also called a tippler system. On the export side of the terminal a marine system utilising vessels is used. The export interface therefore consists of ship loaders. An example of a terminal supplied by trains can be found in Chennai, India, (Figure 5 and 6). In this case it is a iron ore exporting terminal.

For this specific terminal the incoming flow cannot be controlled. Trains arrive with material at times controlled by the mines supplying the ore. One key performance indicator is the total time that the export vessels have to wait before they are completely serviced. A simulation model has been made that is based on the model shown in Figure 3 that was used to study the effect of the ship loading capacity, maintenance policies and bypassing options on the times export vessels are at the terminal. These times are the sum of the time a vessel has to wait before it can be serviced, the time it takes to moor and leave the harbour, and the time a vessel is effectively loaded.

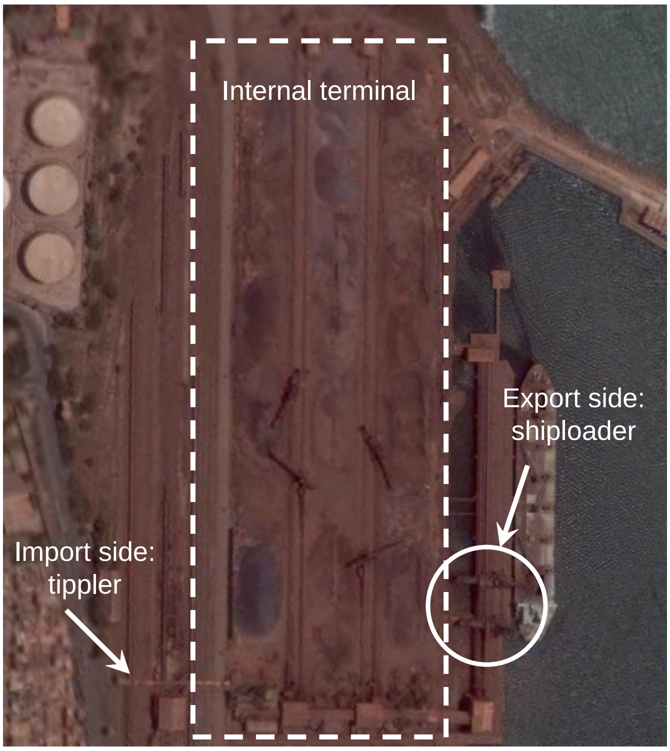

Figure 5: Railway system on the import side and a marine system on the export side of a bulk terminal

Figure 6: Wagons filled with iron ore waiting to be offloaded

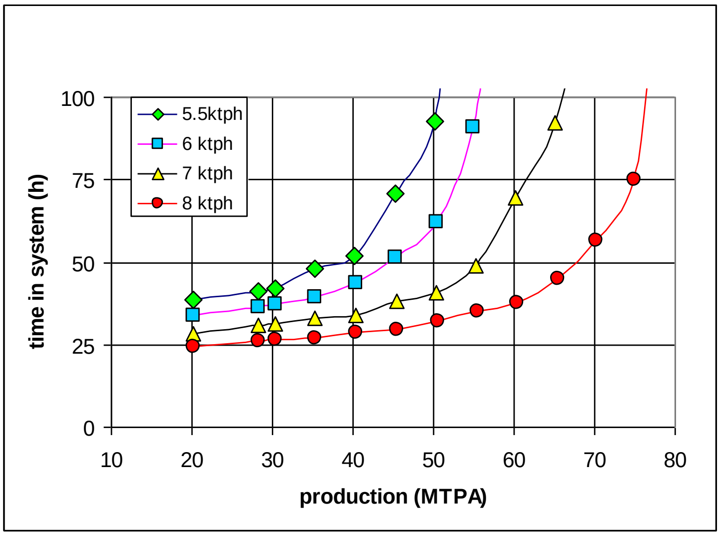

Figure 7: Service times of export vessels as a function of the loading capacity

Figure 7 shows the times export vessels are at the terminal as a function of the terminal throughput for various ship loading capacities. As can be expected, the average time export vessels are at the terminal decreases with an increase in loading capacity. Assuming that the number of loading positions are fixed at two, it can also be seen that the service time increases with an increase in annual throughput of the terminal. This is caused by an increase of the berth occupancy. If the berth occupancy increases then, in particular when the berth occupancy exceeds the 50%, the waiting time of vessels before they can be loaded increases exponentially. This is primarily caused by the stochastics of the arrival patterns of vessels and the variation in loading times of vessels, which was discussed in Section 3. Depending on the service level a terminal wants to offer in terms of service time, Figure 7 can be used to determine the loading capacity and thus the number of ship loaders that are required as well as their loading capacity. If for example the terminal considers a service time of 40 hours acceptable, then the maximum throughput the terminal can handle is 50 MTPA with a loading capacity of 7,000 TPH. In practice this could mean that two ship loaders with a capacity of 7,000 TPH need to be installed.

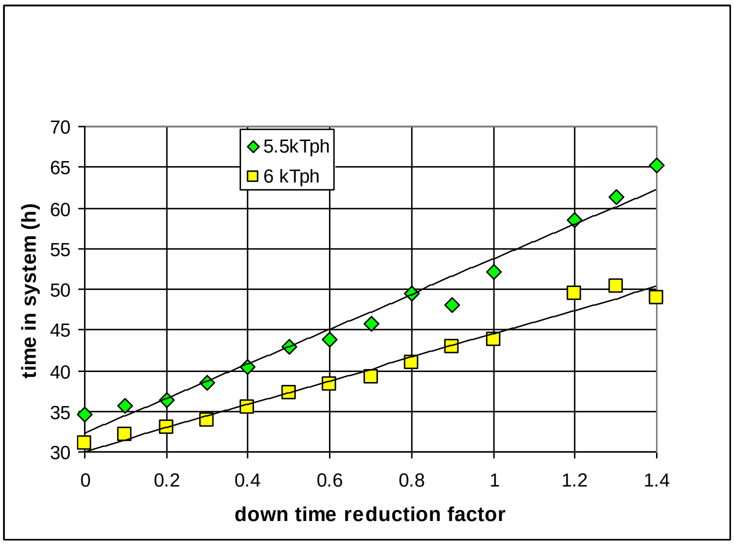

Figure 8: Service times of export vessels as a function of maintenance policies

Figure 8 shows the effect of a change in maintenance policy on the time vessels are at the terminal. The effect of a change of maintenance policy is visualized as a change in the downtime factor, 1 being the downtime factor realized with the current maintenance policy which can be described as a corrective maintenance policy [4]. If, for example, the maintenance policy would be changed from corrective maintenance to predictive maintenance, the downtime factor would be reduced to 0.2. This effectively means that, with a loading capacity of 6,000 TPH and an annual throughput of 40 MTPA, the times vessels are at the terminal decreases from about 45 hours to 33 hours. Whether the extra maintenance effort is worthwhile depends among other issues on who pays for the waiting times of vessels.

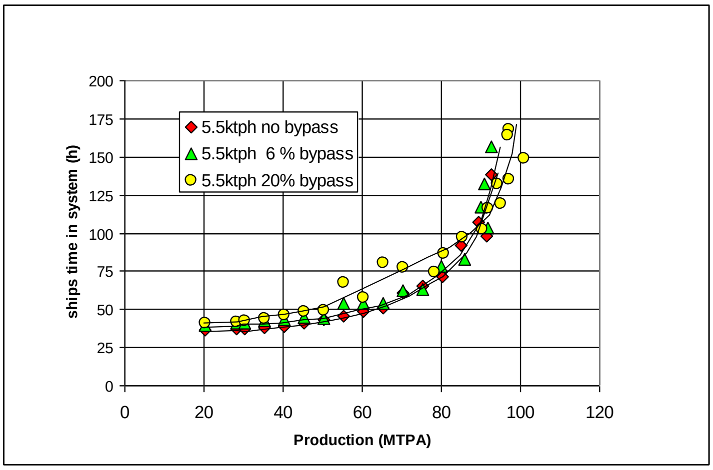

Figure 9: Service times of export vessels as a function of bypass options

Figure 9 finally shows the effect that bypass options have on the times vessels are at the terminal, in this case with a loading capacity of 5,500 TPH. By-passing in the terminal context means that bulk material is directly routed from the tippler to the ship loader, effectively by-passing the internal terminal system. In case of by-passing, the bulk material is not stacked and reclaimed when needed. Varying from no by-pass, to 6% of the throughput by-passing to 20% of the throughput by-passing, it can be seen that by-passing does not have a significant effect on the times vessels are at the terminal. By-passing in practice is difficult because it requires a solid logistic control of the bulk material being delivered on the import side and bulk material being requested at the export side. The advantage of by-passing is that it decreases the utilization of the internal terminal system, which could mean that the terminal can decrease in size and capacity.

5. BELT CONVEYOR SYSTEM

The second example mentioned in the introduction is a dry bulk terminal with a belt conveyor on the import side. An example of a bulk terminal that is supplied with bulk solid material, in this case coal, by a belt conveyor on the import side can be found at the Kaltim Prima Coal Mine and terminal in Indonesia. The Kaltim Prima coal mine is connected to a bulk terminal by means of a belt conveyor system. Figure 10 shows a schematic drawing of the terminal system. The material flow is directed either to a stockpile via a stacker system or can be by-passed for direct loading into a ship. Stacking is done if there is no ship available or if the downstream line is blocked by disturbances of the downstream equipment.

An initial study was performed into the performance of the bulk terminal [5]. The equipment reliability played an essential role in the performance of the terminal. The first step was to investigate what terminal size was required in order to decouple the export side from import side as discussed before.

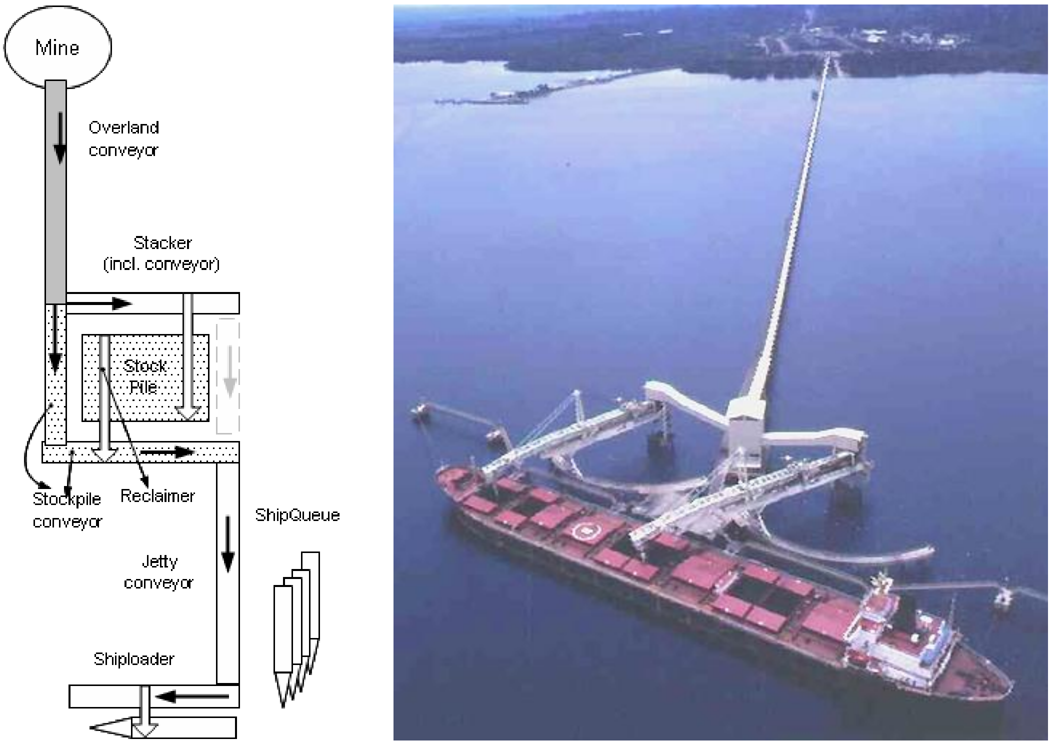

Figure 10: Belt conveyor system on the import side and a marine system on the export side of a bulk terminal

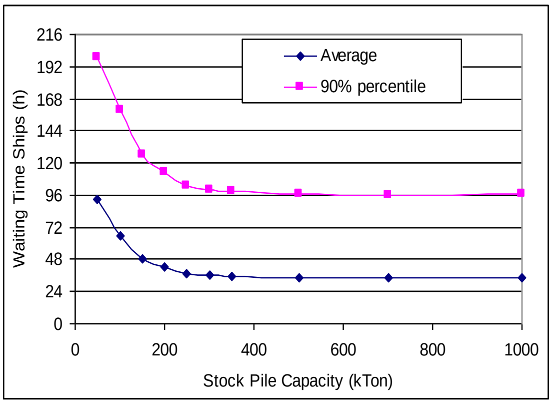

Figure 11: Ship-Waiting Times as a Function of the Stockpile Capacity

Figure 11 shows the relation between the waiting times of export vessels and the size of the stockyard. From this initial analysis of the export section it was determined that the minimum terminal stockyard size should be 350,000 ton. As can be seen in Figure 11, the waiting times become pretty much constant after 350,000 ton. Figure 11 shows both the average ship waiting times and the 90% percentiles of the waiting times. The fact that the waiting time of vessels does not go down to zero is caused by the fact that only one berth is realised and the remaining waiting time is related to the berth occupancy. What is important to realise is that with a stockpile size over 350,000 ton, vessels never have to wait because the terminal runs out of stock.

From this minimum stockyard capacity the sensitivity to the reliability of the import belt conveyor needs to be investigated. Starting from a reliability of 97%, the reliability was changed to investigate the effect on the times the stockpile was empty and the waiting times of vessels. Figure 12 shows the percentage of time the stockpile has been empty and consequently could not function well. It appears that the reference availability values have some margin of 1 % left. If the availability of the import belt conveyor decreases with more than 1 %, so if it is less than 96%, the stockpile is liable to run out of stock. As may be expected, if the availability is increased nothing happens. As discussed in Section 4, availability of equipment depends on the maintenance policy.

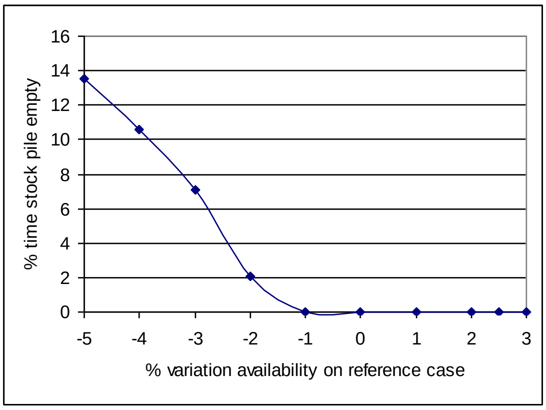

Figure 12: Percentage of time the stockpile was empty as a function of varying equipment availability

Finally the influence of availability variations on the ships waiting times are determined. The results are given in Figure 13 showing that the average ship waiting time for the reference case will be about 36 hours. A demand on the customer service may be that the average waiting time of ship before loading should not exceed 36 hours. If this demand for example is 24 hours, then a way to reduce the waiting time down to 24 hours is to improve the availability by about 2.5% by improving the logistic control of the maintenance procedures, or to increase the capacity of the system components. The latter seems a better option for this system considering the fact that an increase in availability from 97% to 99.5% seems rather unlikely.

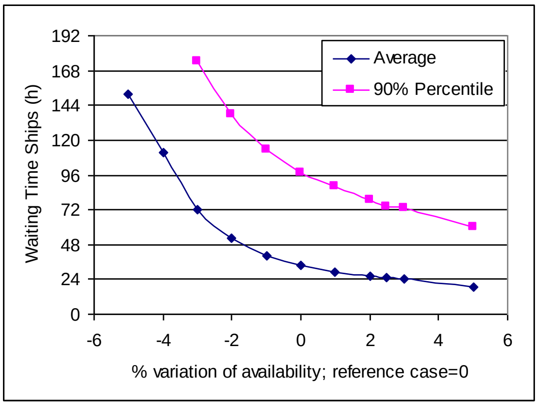

Figure 13: Ship waiting times as a function of varying equipment availability

6. MARINE SYSTEM

The third and last example announced in the introduction is a terminal with a marine system on the import side; see the Figures 14 and 15. The terminal shown is the EECV terminal in Rotterdam, the Netherlands, handling primarily iron ore and coal. A similar terminal was studied with a simulation model based on the model shown in Figure 3. It was assumed that the terminal has a throughput of 30 MTPA and one import berth. The study was aimed at the determination of the effect of the logistic control of the import flow of bulk material on the performance of the terminal. The key performance indicator in this case is the waiting time of vessels.

Figure 14: Marine system on the import side and a marine system on the export side of a bulk terminal

Figure 15: Three ship unloaders working simultaneously on one CapeSize vessel

Waiting times of import vessels
as a function of berth occupancy

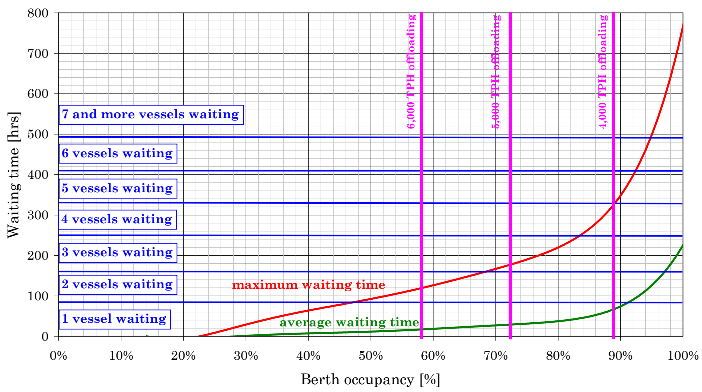

Figure 16: Waiting times of import vessels as a function of the berth occupancy

Figure 16 shows the waiting time of the import vessels as a function of berth occupancy. In addition it shows the number of vessels waiting and the actual berth occupancy for three different offloading capacities. For example, at an offloading capacity of 6,000 TPH the average waiting time of import vessels is about 20 hours. If the offloading capacity is 4,000 TPH, then the average waiting time increases to about 85 hours. With berth occupancy less then 23%, import vessels never have to wait. This means that, with an offloading capacity of 6,000 TPH, if the number of offloading positions is increased from 1 to 3, import vessels never have to wait.

Figure 17: Waiting times of import vessels as a function of the time window

Even if vessels arrive more or less according to a time schedule, the exact time of arrival is not known. They can be on time, but also too late or too early. Depending on the length of the journey, ambient conditions, and the ability of the terminal to affect arrival times of vessels, vessels may be expected to arrive in a certain time window. If the arrival time can be predicted exactly, then the time window is 0. If the arrival time is less predictable, then the time window increases. Figure 17 shows the effect of the time window on the waiting time of import vessels at an annual throughput of 30 MTPA. With a time window of 0 it can be seen that the waiting time is 0 as well. In that case the time it takes to service a vessel is less than the time between arrivals of adjacent vessels. If the time window increases then it can be seen that vessels arrive before the previous vessel is serviced causing waiting time. The less predictable the arrival times of vessels, the longer the average waiting time. If the import flow can be controlled well logistically then waiting times can be minimised.

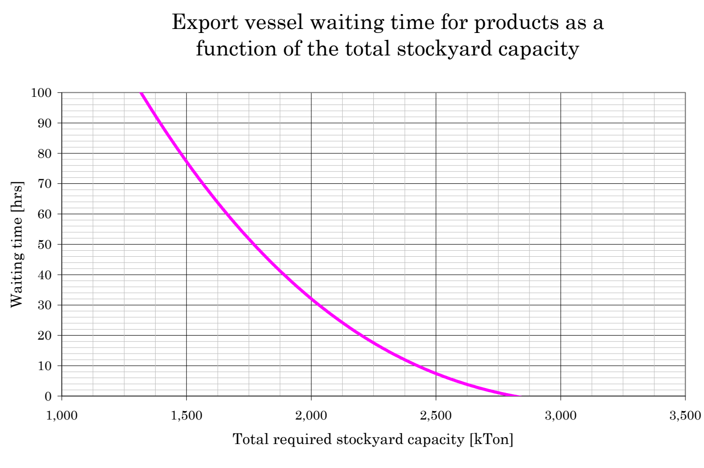

Figure 18: Average waiting times of export vessels as a function of the stockyard capacity

Figure 18 finally shows the effect of the terminal stockyard size on the waiting times of the export vessels. As discussed in Section 3 the import flow is decoupled from the export flow only if there is always enough bulk material of the right sort available for the export. From Figure 18 it can be learned that, for this terminal with an annual throughput of 30 MTPA, the import was decoupled from the export if the stockyard exceeds 2,8 million ton. As a rule of thumb, a terminal stockyard size is about 10% of the annual throughput. For this terminal, that would mean that import and export are decoupled so export vessels never have to wait for products. With proper logistic control, the stockyard size of a terminal can be significantly lower than 10%. The fact that the waiting times in Figure 18 go down to zero indicates that berth occupancy of the export berth is low.

7. CONCLUSIONS

The logistic control of bulk terminals, in particular the controllability of the import flow and the maintenance control, has a significant impact on the performance of a dry bulk terminal. Key performance indicators used in this respect are waiting times of transport equipment used on the import and export side of the terminal. Also the design of the terminal has a significant effect on the performance of the terminal. In particular the terminal size, in terms of percentage of the annual throughput, and the capacity of the handling equipment affects the terminal's performance. The effects of both the logistic control and the design on the terminal's performance are of the same order and should be studied together when designing a new or upgraded terminal. The utilization of logistic simulation tools in the design process is a prerequisite for the design of a logistically sound terminal.

8. REFENCES

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