Measuring and Improving Dry Bulk Terminal Performance

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At dry bulk terminals, several bulk materials are simultaneously transported using belt conveyors. Serving ships on time and at correct speed is crucial for terminal operators. To measure and control the terminal performance, a performance indicator is required. This paper presents an approach to assess the terminal performance by monitoring the performance indicators quay occupancy, availability losses and speed losses during ship unloading. This approach is based on the Overall Equipment Effectiveness (OEE), to observe as soon as possible deviations from the desired operation with an indication of the possible cause. Basically, the OEE represents the net unloading capacity in percentage of the maximum unloading capacity by monitoring and registering operational data of active processes at the terminal. For a specific dry bulk terminal, the OEE has been derived for several years and the results are discussed.

Keywords:* *terminal performance, Overall Equipment Effectiveness, ship unloading, dry bulk terminals.

I. INTRODUCTION

Dry bulk terminals located near deep sea are used around the world to handle large quantities of bulk materials like coal and iron ore. These terminals are used worldwide as a buffer between an incoming flow and an outgoing flow of bulk materials [1]. Another function of these terminals is to store the bulk materials temporarily for their clients; coal-fired power plants or steel factories. At some terminals, the materials are blended or homogenized to obtain the right material properties for using in blast furnaces of steel factories or in the pulverized fuel mills of thermal coal-fired power plants.

Dry bulk terminals are complex logistic systems where a lot of material transport activities have to be performed simultaneously using a network of belt conveyors. For example; (i) transporting of materials from ships to the stockyard, (ii) transporting of materials from the stockyard to blending piles and (iii) reclaim and transport materials from the blending piles to a steel factory. Dry bulk terminals are faced with uncertainties. The arrivals of ships are stochastic, which means that the exact arrival time at the quay differs from the scheduled arrival time. Another source of uncertainty is that the machines and the belt conveyors break down unexpectedly or need maintenance. Moreover, several different types of bulk materials are handled, having specific handling characteristics, which results in different handling and transporting capacities.

Unloading of ships is performed by large cranes; see Fig. 1 where a ship is unloaded at the Tata Steel terminal in IJmuiden. The handling of materials at the stockyard is carried out by huge stacker/reclaimers (machines which are able to stack and reclaim), or blending machines. Troughed belt conveyors are used for transporting the materials between machines.

FIGURE 1: UNLOADING A SHIP AT THE TATA STEEL TERMINAL

Fast unloading of ships is vital for terminals because of the high demurrage costs, which are actually penalty costs if the unloading of ships requires more time than previously agreed between the ship-owner and the terminal operator. Therefore, terminal operators are willing to unload the ships as fast as possible to avoid that next ships have to wait before getting serviced. That's why a typical terminal performance indicator is the average waiting time of the ships [2] [3].

However, this performance indicator assesses only the performance of the seaside of the terminal. A terminal has to perform a number of activities simultaneously which affects the seaside performance. This paper presents an approach to determine the terminal performance by monitoring active processes. This approach is based on the Overall Equipment Effectiveness (OEE), but specified for dry bulk terminals.

This paper is organized as follows. Section II proposes the Overall Equipment Effectiveness for a dry bulk terminal.

Section III describes a method to monitor and register operational terminal data, which is needed to determine the OEE. Section IV investigates the OEE for the Tata Steel terminal in the Netherlands and introduces solutions to increase terminal performance. Finally, Section V provides conclusions and directions for future research.

II. Overall Equipment Effectiveness

Overall Equipment Effectiveness (OEE) began to be recognized as a fundamental method for measuring plant performance in the late 1980s and early 1990s. The OEE helps understanding how well a manufacturing system performs, and identifies what is limiting higher effectiveness [4]. Transporting, handling and blending of bulk materials at a dry bulk terminal can be considered as a manufacturing process and the OEE can be used to measure terminal performance.

The terminal OEE expresses the efficiency of the entire terminal into a single number during ship unloading. As already mentioned in the previous Section, serving the ship on time and at correct speed is crucial for terminal operators. Therefore, the OEE analysis will mainly focus on the ship unloading activity with respect to the connected transport system. Basically, the OEE represents the net unloading capacity in percentage during the planned unloading time compared with the maximum unloading capacity. Fig. 2 shows the graphical representation of the OEE (OEE structure) with definitions.

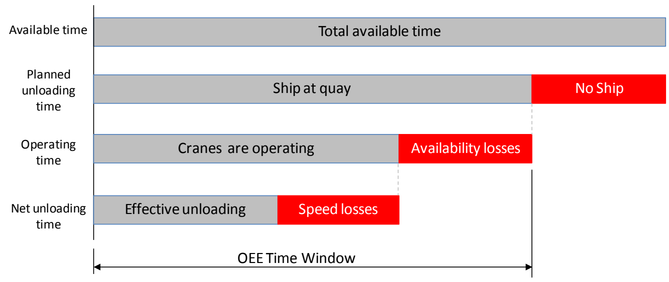

Figure 2: OEE Structure

The total available time is the entire period when the terminal is in operation (mostly 24 hours per day and 365 days per year). The planned unloading time represents the time when at least one ship is berthed at the quay. The operating time is the time when the cranes unload. Availability losses happen if a ship is berthed at the quay while the cranes cannot operate due to; (i) malfunctions in the transport system (conveyors) or stockyard machines, (ii) planned maintenance, (iii) human errors, bad weather conditions (too much wind, ≥ Beaufort 8 [5], or fog) or (iiii) technical failures of the cranes.

If cranes are unloading ships, the real unloading capacity is mostly lower than the maximum unloading capacity (free-digging capacity). Cranes are only able to reach the maximum unloading capacity during unloading of the upper part of the hold. The unloading capacity reduces significantly if there is less cargo in the ship; longer lifting distances of the grab and more difficulty for filling the grab completely (see Fig. 3). This loss is indicated as Speed losses.

Verschoof has determined for medium-sized bulk carriers the unloading curve during iron ore unloading under very-good conditions [5]. Fig. 3 shows the unloading curve. Only 50% of the load is unloaded at free-digging capacity. For the rest of the load, lower capacities are achieved. Especially during the last stage (cleaning or trimming stage) where a dozer is brought into the ship to move the remaining material to the mid of the hold where the crane can grab the material.

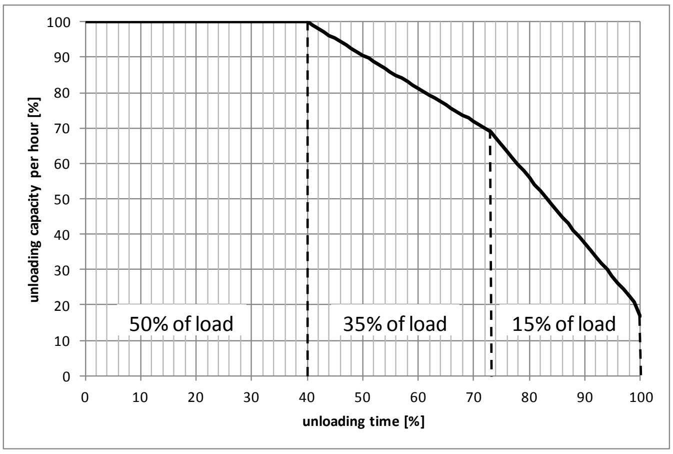

Figure 3: Unloading curve

The OEE of a manufacturing plant (for example a factory) also contains a term which is called quality. This term takes quality losses, products which are manufactured but do not meet the quality standards and have to be reworked or thrown away, into account [4]. However, at a dry bulk terminal all the materials are unloaded from the ship to the terminal, which means that no material is lost and this term can be left out.

The OEE is calculated for the time period that at least one ship is berthed at the quay (Fig.2: OEE Time Window). The time when there is no ship has not a direct consequence on the OEE. Nevertheless, when there is no ship at the quay, maintenance of the cranes is scheduled. If the quay is almost 100% of the time occupied, maintenance have to be carried out when the cranes have to unload, and this will decrease the OEE. The OEE can be calculated with the following formula:

$$\text{OEE} = \text{Availability} \times \text{Performance} \qquad (1)$$

Availability and *Performance* are common terms at dry bulk terminals to express respectively the time that cranes are available to unload and the net unloading capacity compared to the free-digging capacity.

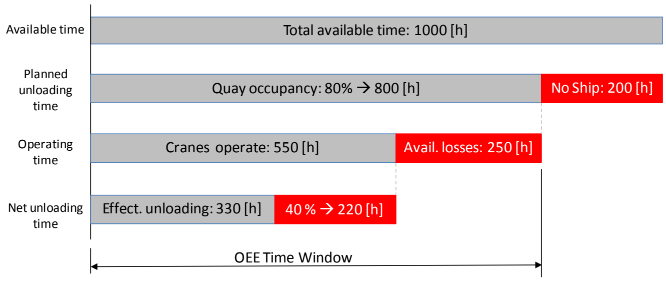

FIGURE 4: EXAMPLE OF AN OEE CALCULATION

Fig. 4 shows an example for the determination of the OEE. Assume that during a period of 1000 hours, the quay is occupied for 80%, which means that during 800 hours at least one ship was berthed at the quay. From the 800 hours, the cranes unload 550 hours, which results in an availability of 69% (550/800). During unloading, the effective unloading capacity was 60% of the free-digging capacity, which means that speed losses were 40%. If the cranes were able to unload with free-digging capacity, only 330 hours were needed. In this case the OEE is 41% (0.69 x 0.6 or 330/800).

III. TERMINAL OPERATIONAL DATA

This Section illustrates which operational data is required to determine the performance indicators; quay occupancy, availability losses and speed losses. These performance indicators are used to determine the OEE.

A. Quay occupancy

As already mentioned, terminal operators attempt to unload ships as fast as possible to prevent large waiting times of ships. It is preferred to maintain the cranes when there are no ships to unload. To gather operational terminal data, which determines the quay occupancy, the lay time of ships at the quay must be registered. For further analysis, the unloaded tons per ship and the material type, to consider later the specific material handling characteristics, must be recorded.

B. Availability Losses

The availability losses stand for the time that there is no unloading activity while there is a ship available at the quay. These losses can be determined by measuring the activity of the cranes, with at least one ship at the quay. A possibility to measure the crane activity is to mount a sensor in the trolley of the crane which records the trolley moves, see Fig. 4. The availability losses can have several reasons, which are already mentioned in Section II, and these losses must be logged separately to determine specific causes.

One of the major availability losses are transport losses, which are caused during transporting the materials using a route of interconnected belt conveyors. While collecting detailed operational data, insight is gained which route performs well and which individual belt conveyor disturbs many times and needs extra maintenance. Generally, more routes can be used to transport materials, so the used route must be determined. Fig. 5 shows an example where already 5 routes are possible from the quay to stockyard machines M1 or M2; (1,4,6,8), (1,3,5,8), (1,3,7), (2,3,7) and (2,4,6,8).

In Fig. 5, two ships (S1 and S2) are unloaded simultaneously. The bulk materials from ship (S1) are unloaded by crane (C1) and transported with belt conveyors (2, 3 and 7) to the first stockyard machine (M1), which stacks the material at the first stockyard lane (L1). To measure if C1 cannot unload because of a hindrance in the transport system (conveyors 2, 3 and 7) or stockyard machine (M1), the activity of these components must be registered during the entire unloading cycle. If for example, belt conveyor (3) is not active during a certain part of the unloading cycle, this conveyor caused the stoppage of C1. The lost unloading time can be specified as a transport loss due to conveyor (3).

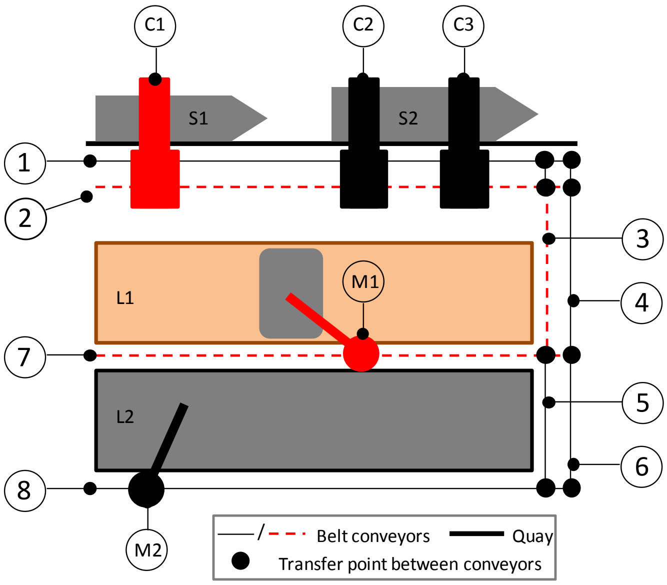

FIGURE 5: SCHEME OF A DRY BULK TERMINAL

C. Speed Losses

Speed losses are determined when a crane is assigned to a ship, and the crane is active and operates (trolley moves) but with a lower capacity, in tons per hour, than the free-digging capacity. Several reasons can be distinguished; (i) the stage of the unloading cycle (already mentioned in Section II, and more details can be found in [5]), (ii) some materials have poor handling characteristics (e.g. sticky), (iii) the ability of the crane driver and (iiii) the hindrance of the transport system. If the maximum transport capacity of belt conveyor (3) of Fig. 5 is 1,500 [t/h] and the crane free-digging capacity is 2,000 [t/h], the crane is hindered by the belt conveyor (3) to perform at its maximum speed. The net unloading capacity can be measured by recording the transported tons over the connected conveyor which is equipped with belt scales, see Fig. 6.

IV. EXPERIMENTAL EVALUATION

The material transportation department of Tata Steel in IJmuiden uses the OEE for several years to measure and improve dry bulk terminal performance. This Section introduces the terminal of Tata Steel in the Netherlands and shows how the operational data is obtained to measure the OEE. The measured OEE for the years 2008, 2010 and the first half year of 2011 are determined and solutions are proposed to increase terminal performance.

A. Tata Steel Terminal in IJmuiden

Tata Steel in IJmuiden (the Netherlands) produces more than 7 million tons of steel per year [6]. Large quantities of ore and coal are imported, blended at the terminal and transported to the steel factory. The material transportation department is responsible for all these logistic activities and has developed a program called EVA, which stands for "**E**rtsbewerking **V**oorraad and **A**anvoer" (Ore treatment, Stock and Supply in English). This program is used to monitor the active processes at the terminal and control the stockyard volumes. EVA collects operational data from the entire terminal with in general an interval of 5 minutes and store this data in a database to generate several numbers and figures. Some signals are collected more frequently to guarantee a higher accuracy (the trolley moves) and some signals are just collected once a week (stockyard volumes). Fig. 6 shows a representation of the collection of all equipment signals in EVA.

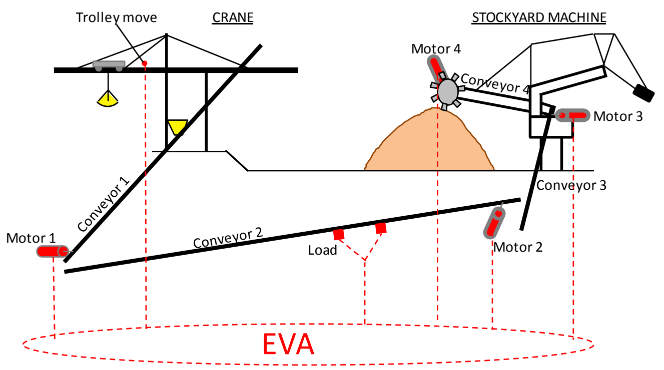

FIGURE 6: GATHERING OPERATIONAL DATA IN EVA

Fig. 6 shows a simplified representation of one route of belt conveyors between a crane and a stockyard machine. The movement of the trolley is recorded to determine crane activity. From each motor of the conveyors 1 to 4, a signal is send to EVA which indicates if the conveyor runs. In each route, one conveyor is equipped with belt scales (Load) for continuously measuring of the transported tons.

B. Measuring terminal performance

An EXCEL tool [7] is developed to generate the OEE structures from the operational data of EVA. Using these structures, Tata Steel determines the OEE and compares the terminal performance for several years.

Fig. 7 shows three OEE structures which are based on the operational data for the years 2008, 2010 and the first 6 months of 2011 (2009 is excluded in this paper because the amount of unloaded materials was significantly lower). The availability losses are divided in (i) transport losses, (ii) technical failures of cranes (f.e. an overload warning or emergency stop), (iii) human, weather and other losses and (iiii) maintenance of the cranes.

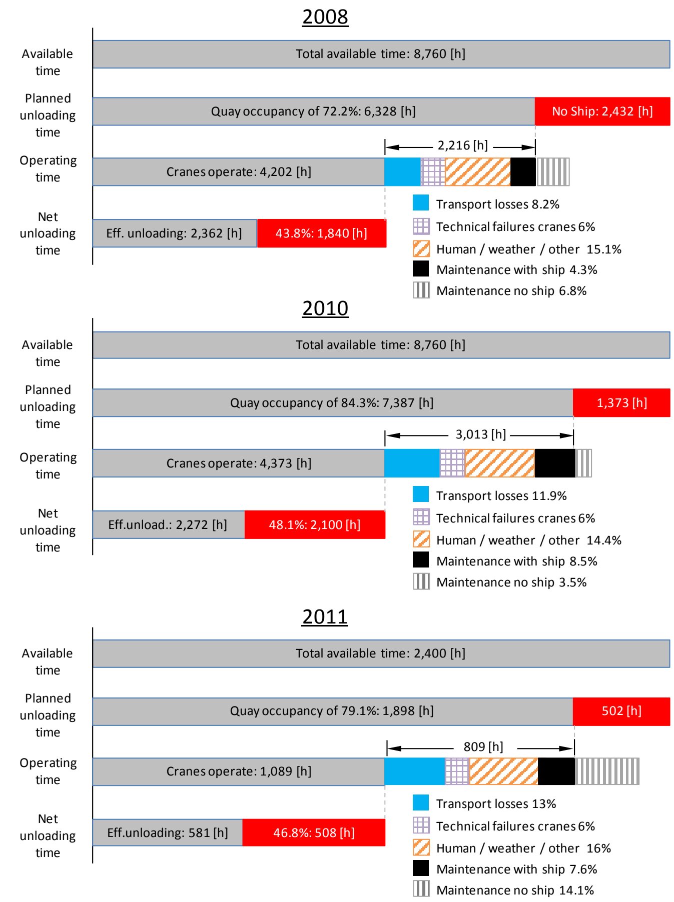

FIGURE 7: OEE STRUCTURES TATA STEEL TERMINAL 2008, 2010 AND 2011

The cranes availabilities, cranes performances and terminal OEE's are derived and shown in Table 1.

Table 1: Availability, performance and OEE

	2008	2010	2011
Availability [%]	66.4	59.2	57.4
Performance [%]	56.2	52.0	53.3
OEE [%]	37.3	30.8	30.6

Considering the OEE structures of Fig. 7 and the results of Table 1, the following remarks can be made:

- The availability and performance and as result the OEE, decreased in 2010 and 2011 compared to 2008.
- The quay was more occupied in 2010 and 2011, which results in an increase of maintenance during an occupied quay. The reason was that in 2010 and 2011 more ships, but with less average tons, were handled in 2010 and 2011 compared to 2008.
- The speed losses are approximately constant for the years and are relatively high, around the 45%. This means that if the cranes operate, the average unloading capacity is approximately 55% of the free-digging capacity.
- The time that the cranes cannot operate due to failures in the transport system (transport losses) increased in the years 2010 (11.9%) and 2011 (13%) compared to 2008 (8.2%).
- The losses due to technical failures of cranes and human, weather and other losses are for the three investigated years approximately constant.
- In 2011, one of the three cranes gets a major maintenance intervention of 3 months which is represented with the large fraction of maintenance time.

C. *Analyzing terminal performance*

The terminal performance decreased in 2010 and 2011 compared to 2008. More maintenance is performed during an occupied quay because of the higher quay occupancy. Another reason is the increase of transport losses. To investigate the causes for these extra transport losses, extra research is required. Firstly, the transport losses are related to the different material types, see Fig. 8.

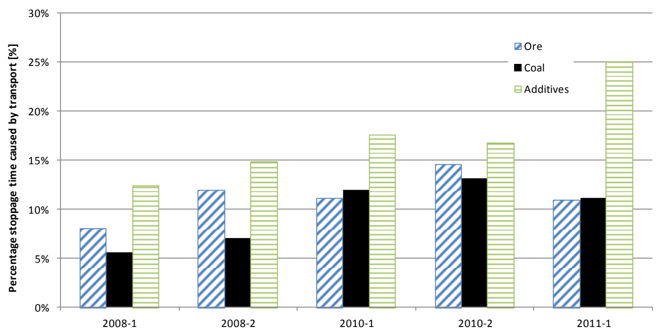

FIGURE 8: PERCENTAGE OF STOPPAGE TIME DURING UNLOADING IN CAUSED BY A TRANSPORT FAILURE

(Additives contain for 90% of iron ore pellets and 10% of olivine, which is added in blast furnaces)

Fig. 8 shows the percentage of time a stoppage of a crane is caused by a transport failure for the three materials ore, coal and additives. In the first half year of 2008 (2008-1), the cranes are stopped during 8% of the total unloading time for ore because of failures in the transport system. Fig. 8 shows also that the transport losses for the three materials are increased. Especially, transporting additives results in many failures. The explanation is that iron pellets (=90% of additives) is only transported over one route. This route is not always available because this route is also used for transport of blended coals to the cokes factory. Moreover, the maximum transport capacity of this route is 2,500 [t/h], which indicates that if additives are unloaded by two cranes, the unloading capacity per crane is limited to 1,250 [t/h].

The transport losses are also compared with the blending activity at the same time. For building up a blending pile, materials are reclaimed and transported from the stockyard. If both activities are performed simultaneously, fewer routes are available. If then a belt conveyor breaks down, less alternative routes remain and this may increase the number of stoppages of the cranes. The EXCEL tool examines when unloading and blending happens at the same time, and determines the percentage of the crane downtime during these parallel activities. Results are showed in Fig. 9, which shows the percentage of crane stoppage time because of a transport failure during simultaneously blending.

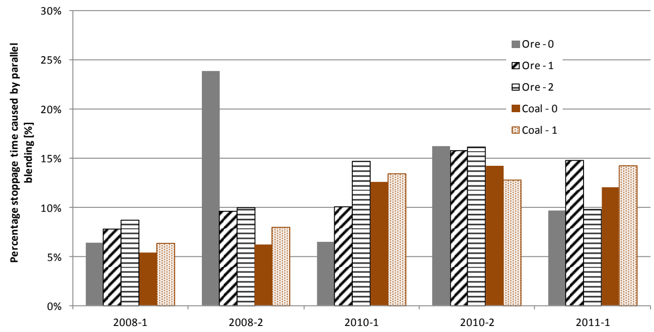

FIGURE 9: PERCENTAGE OF TRANSPORT LOSSES WHILE BLENDING

At the Tata Steel terminal there are three blending piles, 2 for blending iron ore and 1 for blending coal. For each half year, the transport losses when no blending (ore-0 and coal-0), or just 1 active blending pile (ore-1 and coal-1) or two active blending piles (ore-2), are considered. The high percentage of stoppages in 2008-2 with no active blending is explained by the small interval between building up blending piles. In this specific period, the steel factory needs a lot of blended ore. If a transport loss happened in the small interval, it resulted in a high percentage of transport loss. In general, Fig. 9 shows that when ship unloading and blending are performed simultaneously, this results in higher percentages of time that cranes are stopped due to failures in the transport system.

At the end, the cranes speed losses are considered related to the three material types. Fig. 10 shows the results.

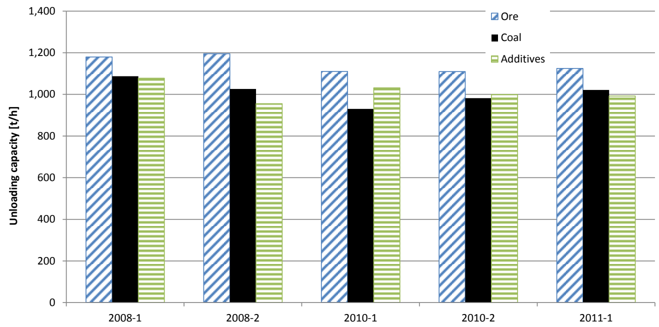

FIGURE 10: UNLOADING CAPACITY PER MATERIAL TYPE

Fig. 10 shows that during unloading of ore, the highest unloading capacity is achieved. The lower unloading capacity of additives is explained because iron ore pellets are also unloaded with the ore grab. Iron ore pellets have a lower bulk density than ore which decrease the unloading capacity.

D. Improving terminal performance

The amount of imported iron ore pellets is increased during the years. In 2010 and 2011, Tata Steel Ijmuiden imports almost three times more iron ore pellets compared to 2008. In the future, this amount will increase. Figure 8 shows that transport of iron ore pellets leads to many stoppages of the cranes because of transport failures. To decrease the losses during the transport of pellets, the transport capacity must increase from 2,500 [t/h] to at least 6,000 [t/h], which enables unloading pellets with three cranes. Nowadays, already 7% of the time when there is at least one ship at the quay, iron ore pellets are unloaded.

Figure 10 shows the low unloading capacity of iron ore pellets compared to ore and coal, although pellets can be unloaded easily. The solution is to use a grab with a higher volume.

To decrease the maintenance during an occupied quay, the quay occupancy must decrease. A solution is to unload less ships but with a larger quantity per ship. Another advantage of a lower quay occupancy is a reduction of the times when simultaneously blending and unloading happen.

V. CONCLUSIONS AND FUTURE RESEARCH

This paper presented an approach to assess the dry bulk terminal performance by monitoring the performance indicators; quay occupancy, availability losses and speed losses. The basis for this approach is the Overall Equipment Effectiveness (OEE), which is used as a structured method to measure the unloading effectiveness of ships. The major losses during ship unloading are divided in availability losses (cranes are not available to unload) and speed losses (cranes unload but with lower speed).

The OEE is used to determine the performance of the Tata Steel terminal in the Netherlands. The OEE decreased in 2010 and 2011 compared to 2008. Further analysis shows that the main causes are the increase of the quay occupancy (less time available to do crane maintenance) and the larger amount of imported iron ore pellets. Improvements can be made by using a bigger grab for iron ore pellets and by upgrading the route, which is used for the transport of iron ore pellets.

Better simultaneous blending and unloading will be a part of future research. Can the blending time be reduced, which reduces the possibility of the parallel actions? How to upgrade the network which decreases the impact of one conveyor break down during simultaneously blending and unloading?

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