Dry Bulk Terminal Characteristics

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Abstract

Due to the high demand for energy and steel new dry bulk terminals will have to be built and existing terminals are being forced to expand. Due to the absence of a comprehensive and detailed design method of dry bulk terminals, designs are mostly based on rules of thumb and practical experiences. In this paper 49 terminals are studied using various references, like annual reports, port authorities' information and Google Earth, to characterize a terminal. Two main types of terminals are distinguished; import and export terminals. Typical terminal characteristics like the annual throughput, installed equipment capacities, quay length, storage factors and the maximum storage capacity are determined. Some rules of thumb from several literature sources are verified but these match poorly with the current terminals. If the determined characteristics are used for terminal design, the designs may vary significantly considering the large range of these characteristics. The determined capacity factors and the relations between the equipment capacities can be used as guidelines for calculating the equipment capacities. Another finding of the research is that at import terminals the installed stockyard equipment capacity is twice as high as for export terminals, to handle the same annual throughput. Finally, a view of the future research is given.

1 INTRODUCTION

To meet the growing global demand of bulk commodities like coal and iron ore, in the future the volumes of the coal and iron ore supply chains are being forced to expand. The entire supply chain consists of all actions from the mine production to the power plants and steel factories. This paper studies only the potential development of dry bulk terminals, referred as terminals in this paper.

1.1 Dry bulk terminals

Dry bulk terminals are used worldwide as a buffer between an incoming flow and an outgoing flow of bulk solids materials (Lodewijks et al., 2009a). The function of the stockpiles at the terminal is to enable transportation facilities with different times and rates of working to function independently of each other, so to avoid delays caused by one facility having to wait for another (UNCTAD, 1985).

In order to enable a proper analysis of a dry bulk terminal, the terminal as a system is modeled as a black box following the Delft systems approach (Veeke et al., 2008). If the black box operational system is opened, three sub-systems can be distinguished; the import system, the internal terminal system and the export system. Depending on the type of terminal, the import and the export system is the seaside or the hinterland side of the terminal, see figure 1.

With nearly 95 per cent in 2008, the shipments of coal, iron ore and grain reflected by far the most important shipping demand in dry bulk trades (ISL, 2009). This paper focuses on terminals which handle iron ore and/or coal. These terminals have a similar footprint since iron ore and coal are typically stored in open storage.

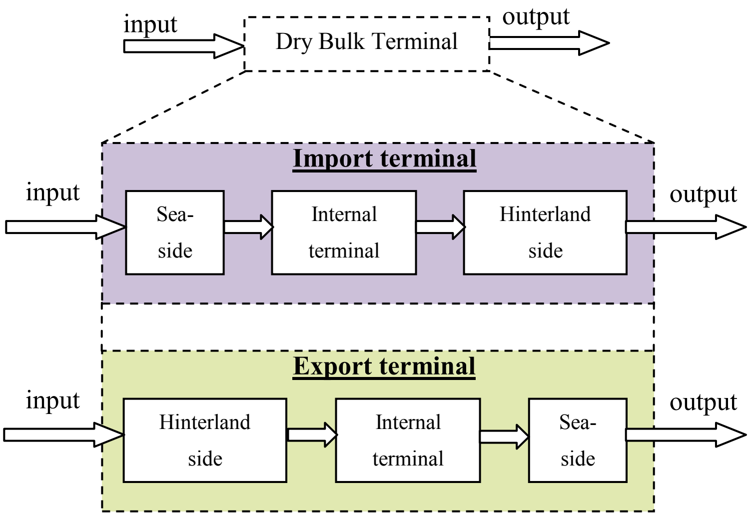

Fig. 1: Dry bulk terminal

1.2 Terminal design methods

Despite of several rules of thumb and formulas, presented by The United Nations Conference on Trade and Development (UNCTAD, 1985), Memos (Tsinker, 2004), (Kraaijeveld van Hemert, 1984) and (Ligteringen, 2000), it is hardly possible to design a terminal with this information. In practice the design of a terminal is based on practical experience and rules of thumb. Previous studies have shown that changing the logistic control of a terminal, can increase the utilization of the machines and determine the success of a terminal (Lodewijks et al., 2009a) and (Lodewijks et al., 2009b).

1.3 Objective of this paper

The objective of this paper is to gather and analyze real-world data of current terminals around the world. From this information, several characteristics have been determined and compared with some rules of thumb and common literature's values.

1.4 Working method and paper outline

From 49 terminals, which handle coal and iron ore, detailed information is gathered from websites, annual reports, port authorities and specialist literature. The terminal dimensions (lane length, lane width, quay length and storage area for coal or iron ore) are examined using Google Earth (http://earth.google.com).

For each terminal the total installed equipment (unloading, loading, stacking and reclaiming) capacities are investigated. The total capacity is the sum of the individual machine capacities per terminal. The total installed equipment capacities are showed as data points in the figures see for example figure 2. To exclude the exceptions, 90% of the data points are fitted between a minimum and maximum limit, these limits are showed as lines in the capacity figures.

The total installed equipment capacity per terminal is compared with the minimum required capacity, represented in figure 2 with the minimum capacity line. This line indicates the minimum required capacity as a function of the annual throughput per terminal if the machines operate the entire year (365 days and 24 hours per day). For example, if a terminal has an annual throughput of 30 million tons, the minimum required capacity is 3,425 [$30*10^6 / (365*24)$] tons per hour (t/h).

Equipment capacity factors, which represent the ratio between the installed and minimum capacity of a certain type of equipment per terminal, can be derived using the following procedure. The minimum and maximum limit for this factor is the ratio between the limits of the installed capacity (B) and (C) and the capacity if the machines operate continuously (A), see figure 2.

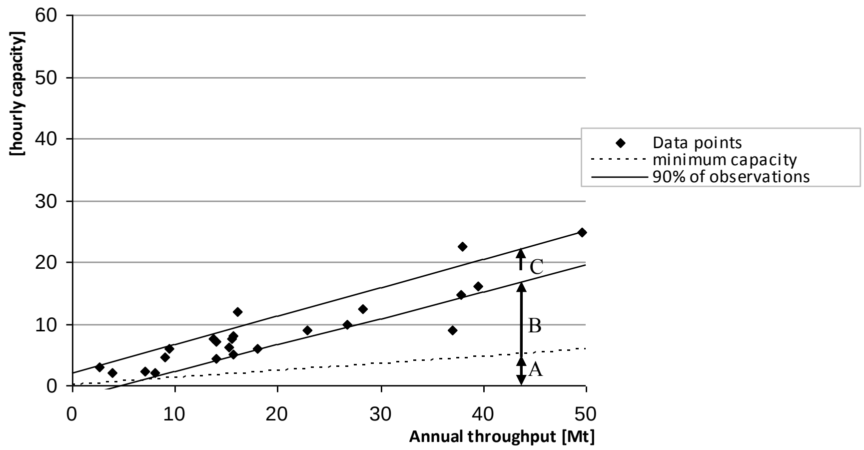

Fig. 2: Derivation equipment capacity factors

The derived unloading, loading, stacking and reclaiming factors will be showed in the following paragraphs.

This paper is organized as follows: section 2 shows general information of the terminals and section 3 presents the characteristics of the sea side of these terminals. The fourth section shows the characteristics of the internal terminal and section 5 presents the hinterland side. Finally, section 6 concludes and incorporates suggestions for continue research on terminal design and operation.

2 INVESTIGATION OF EXISTING DRY BULK TERMINALS

This section shows the locations and main characteristics of the investigated dry bulk terminals. Subsection 2.2 shows the method for the determination of the annual throughput per terminal.

49 terminals around the world are investigated, 23 import terminals, which are represented in figure 3 as blue dots, and 26 export terminals which are showed as red dots. The names, locations and consulted references of the terminals can be requested by the author.

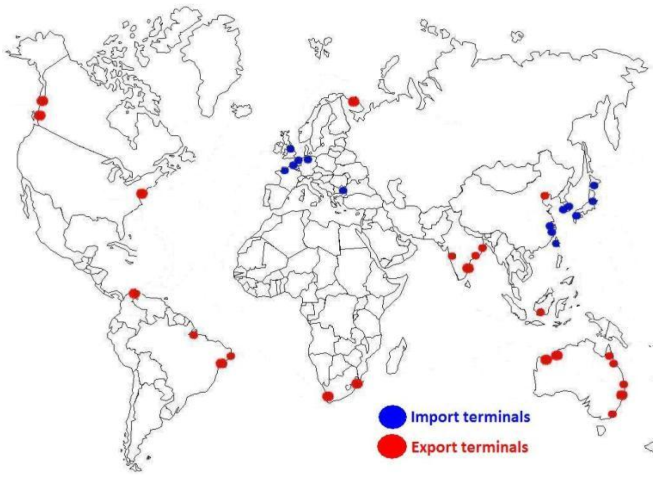

Fig. 3: Investigated dry bulk terminals

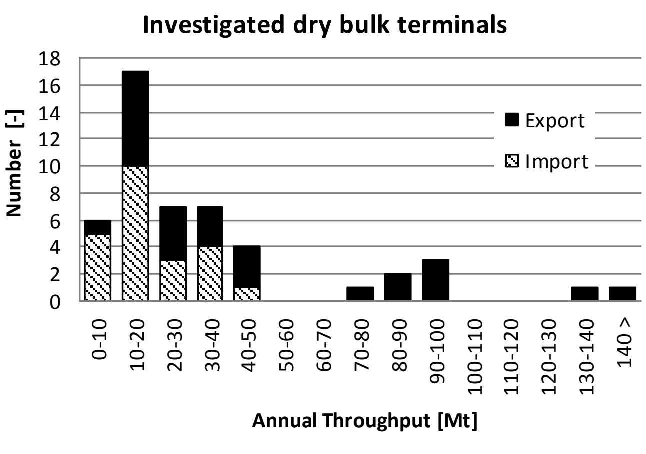

Fig. 4: Number of terminals related to annual throughput

2.1 Main characteristics

The export terminals are mostly situated in Australia, Brazil, South Africa and India and the import terminals are located in Western Europe, Japan and China. The investigated terminals have a similar footprint; a sea side, an internal terminal with mostly stackers and reclaimers and a hinterland side. Details for the seaside, internal terminal and hinterland side will be discussed in the next sections.

2.2 Annual throughput

The throughput values of the year 2008 are taken as the reference value for the annual throughput per terminal. For 45 terminals the annual throughput values for 2008 are found. For 4 import terminals (the Japanese ports of Kashima and Oita and the South Korean ports of Pohang and Gwangyang), the annual throughput values were not found and were not reported after requiring more information.

These four terminals supply materials to steel factories and the annual production of crude steel for 2008 is known. Typically, it takes 1.5 tons of iron ore and about 450 kg of coal to produce a ton of pig iron, the raw iron that comes out of a blast furnace (WSA, 2010). Using Google Earth, these steel factories are all equipped with a coal-fired power plant and for the production of one ton of crude steel, 24 gigajoule (GJ) of energy is required (De Beer et al., 1998). Assuming that all energy for the steel production is generated in the coal-fired power plant on the site, the calorific value of coal is 28 GJ/ton (Worldcoal, 2009) and the boiler efficiency is 45% (Bugge et al., 2005), each ton of produced crude steel needs 1.9 tons of coal.

Figure 4 shows a division of the terminals per annual throughput. The import terminals have an annual throughput up to 50 Mt and the export terminals can have a much larger annual throughput (maximum of 220 Mt for the coal export facilities of the Chinese Port of Qinhuangdao).

3 SEA SIDE

At the seaside of a terminal, bulk carriers are loaded at export terminals or unloaded at import terminals. This section summarizes the details of the seaside concerning the quay length and the installed unloading and loading capacities.

3.1 Quay length factor

Generally, the capacity of a dry bulk terminal depends on the quay length available to ship traffic and cargo handling capacity (UNCTAD, 1985). The terminal capacity relates to the quay length and the quay length factor can be used to derive the required quay length in a new terminal design (Ligteringen, 2000).

The quay length factor (kt/m) is the annual throughput in kilotons divided by the total quay length in meters. Due to the density difference between coal and iron ore, the handled material should be considered in this factor. Export terminals generally handle one type of bulk material; most import terminals handle both commodities over the same quay. A determination of the quay length factor for import terminals related to coal or iron ore cannot be made, only a combined value can be derived.

The lengths of the quays are measured using Google Earth. Figure 5 shows the quay length factors per terminal. The limits for the quay length factor are mentioned in literature for coal, 25 – 75 kilotons per meter (kt/m) and for iron ore 50 – 150 kt/m (Ligteringen, 2000), figure 5 shows also these limits.

If the literature limits are compared with the derived quay length factors, the following conclusions can be made. More than 90% of the analyzed import terminals have a smaller quay length factor (between 10 and 30 kt/m) than the literature limits. For export terminals the quay length factor for coal exporting terminals has a lower value (between 25 and 75 kt/m) compared with the iron ore exporting terminals, which have a quay length factor between the 50 and 150 kt/m.

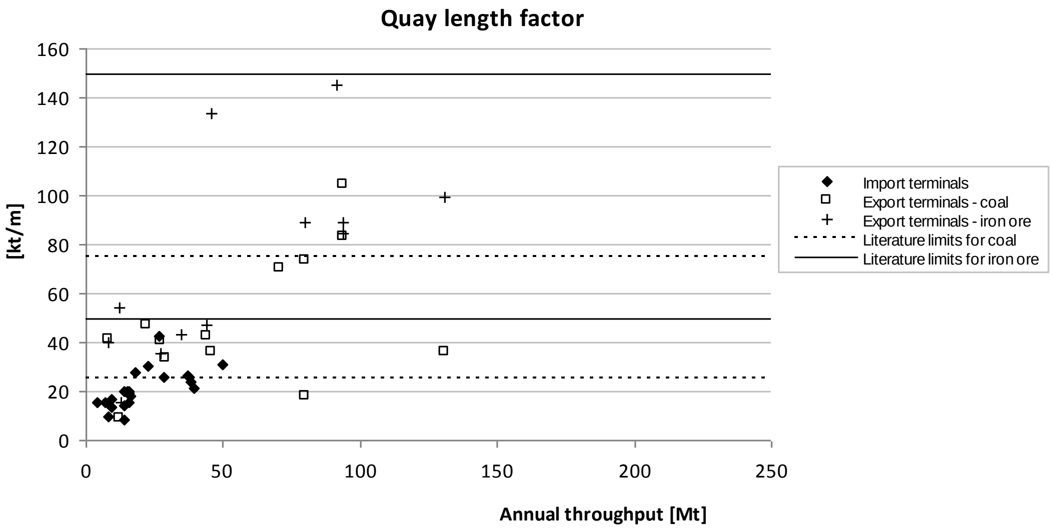

Fig. 5: Quay length factor

3.2 (Un)loading capacities

For each terminal the number and type of unloading cranes and shiploaders, and the total installed (un)loading capacity is investigated. The next figures show the total installed (un)loading capacities in kilotons per hour (kt/h) versus the annual throughput.

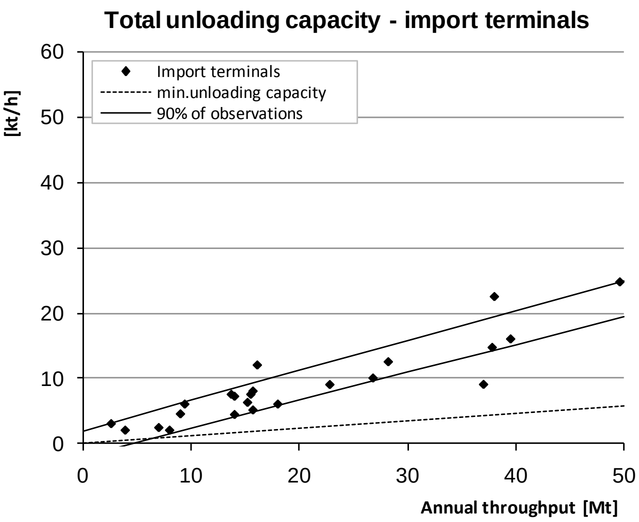

Fig. 6: Unloading capacities at import terminals

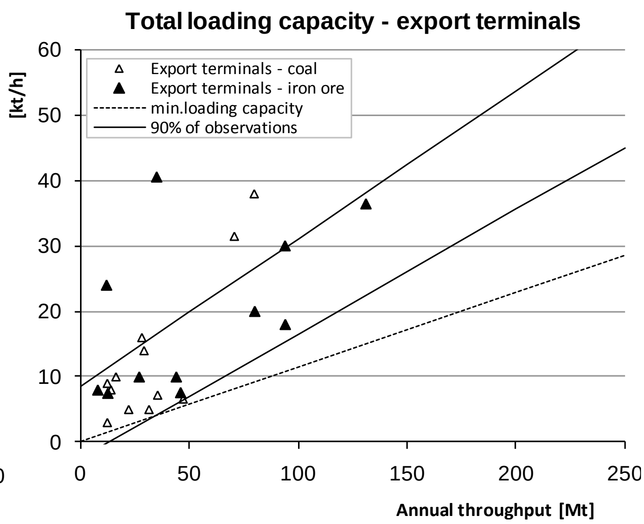

Fig. 7: Loading capacities of export terminals

As expected, the total installed (un)loading capacity per terminal relates to its annual throughput. Figure 6 and 7 show also the minimum required (un)loading capacities and the limits of 90% of the observations. For the investigated import terminals, the unloading factor (the ratio between the installed unloading capacity and the minimum required unloading capacity at the seaside of a terminal) varies between 3 and 4.5. This indicates that the unloading capacity is at least 3 times larger than the minimum required capacity. The loading factor of export terminals varies between 1.5 and 2.5.

4 INTERNAL TERMINAL

The internal terminal connects the seaside and the hinterland side and it consists of a stockyard, which is the buffer between the varying demand and supply. If the storage capacity is insufficient, the situation will occur where either the bulk carrier or the industrial client (steel factory or coal-fired power plant) is kept waiting for cargo (UNCTAD, 1985).

The first subsection derives the storage factor and subsection 4.2 shows the storage capacities of the terminals. Details of the stacking and reclaiming capacities per terminal are listed in subsection 4.3.

4.1 Storage factor

Due to bulk density differences between coal and iron ore, the required storage area per ton differs. The annual throughput per storage area, further referred as storage factor, is determined by the division of the annual throughput and the designated area for coal or iron ore. Rules of thumb for the storage factor are for coal between 15 and 25 tons per square meter (t/m^2) and for iron ore between 30 and 40 t/m^2 (Ligteringen, 2000).

The annual throughput per material is known, see subsection 2.2. Import terminals handle both coal and iron ore, the export terminals handle one type of bulk material. The designated storage area for coal and iron ore is examined using Google Earth. Figures 8 and 9 show the storage factors of both bulk materials for the import terminals and the export terminals versus the annual throughput. The horizontal lines represent the literature limits.

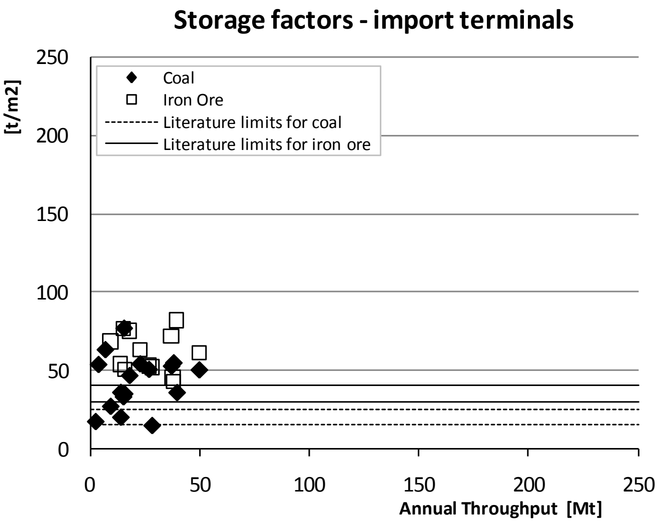

Fig. 8: **Storage factors for import terminals**

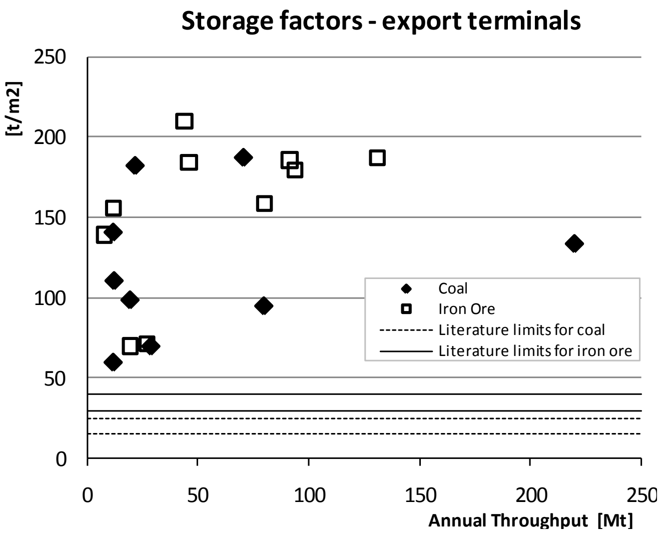

Fig. 9: **Storage factors for export terminals**

Table 1 shows the derived storage factors and the literature limits for coal and iron ore. The derived values are much larger than the literature values, which indicate that the investigated terminals obtain a much higher annual throughput per square meter than expected from literature.

Table 1: Storage factors

Unit: [t/m^2]	Import Terminal		Export Terminal	
	Coal	Iron Ore	Coal	Iron Ore
Analyzed terminals	15 – 75	45 – 80	60 – 185	70 – 210
Literature values (Ligteringen, 2000)	15 – 25	30 – 40	15 – 25	30 – 40

Export terminals have a higher storage factor than import terminals. An explanation is that import terminals are mostly situated near steel factories or coal-fired power plants and have to guarantee a flow of bulk materials. Additional functions, like blending and homogenizing, take also place at import terminals which require extra storage area. At import terminals the material is for a longer period stored at the terminal.

4.2 Storage capacity

The maximum storage capacity is defined by assessing to what extent import fluctuations may be "out of phase" with consumption fluctuations (Kraaijveld van Hemert, 1984). A rough assumption for a coal receiving terminal is a minimum storage capacity of 2 months of the annual throughput. When an even supply of cargo during the year is assumed, it results in a storage capacity of 16% (Kraaijveld van Hemert, 1984). Another reference shows that in the industry a possible stock of about 10% of the annual throughput seems to be accepted (Lodewijks et al., 2009a).

For import and export terminals, the percentages of the storage capacity versus the annual throughput are determined and represented in figures 10 and 11.

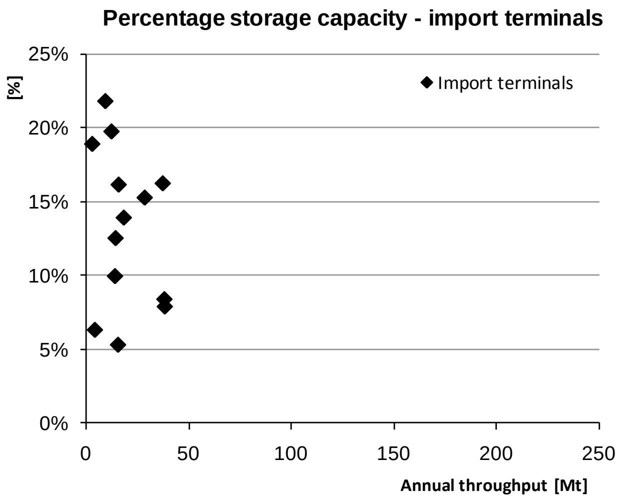

Fig. 10: Percentage of the storage capacity for import terminals

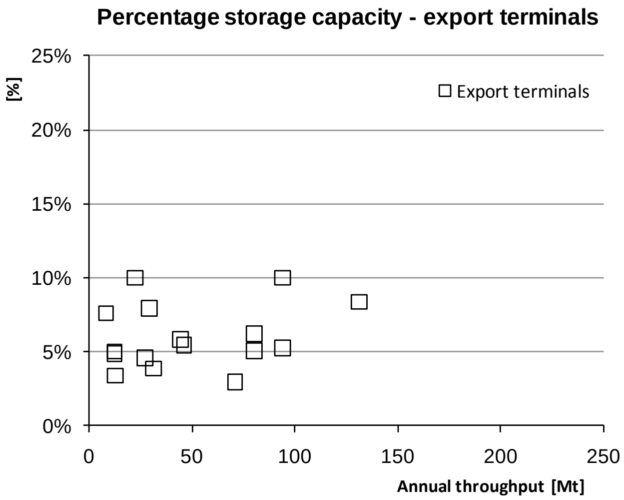

Fig. 11: Percentage of the storage capacity for export terminals

The storage capacity for import terminals varies between 5% and 22% and for export terminals, the storage capacity varies between 3% and 10%. Import terminals have more storage capacity related to their annual throughput in comparison with export terminals for the same reasons as mentioned in subsection 4.1.

4.3 Stacking and Reclaiming Capacities

In a stockpile, bulk materials are stacked to and subsequently reclaimed from a storage facility. The equipment used for bringing the bulk cargo into storage are the so-called stackers. For retrieving material from the stockpile reclaimers are used (Ligteringen, 2000). If the need for stacking and reclaiming at the same time does not arise, then it is recommended that a stacker/reclaimer should be used with reduced initial investment. On the other hand, if both operations are required simultaneously, then separate-function machines are required (UNCTAD, 1985).

For import and export terminals, the stacking and reclaiming capacities are investigated and shown in the figures 12 to 15. The total installed capacity per terminal is the product of the number of machines with their hourly capacity.

For some import terminals the stacking and reclaiming capacities were not found. To get an estimation of the installed capacity, the number of stackers and reclaimers (examined with Google Earth) is multiplied with an assumed hourly capacity for each type of machine (stacker: 2,000 t/h, reclaimer: 1,500 t/h, stacking of a bucket-wheel stacker-reclaimer: 1,000 t/h and for reclaiming of this machine: 750 t/h. A stacker/reclaimer cannot perform stacking and reclaiming at the same moment, that's why it is assumed that half of the time the machine stacks and half of the time it reclaims).

It is assumed, that the entire annual throughput is stacked and reclaimed at the stockyard. In practice, typically by-pass (no storage at the stockyard) percentages in terms of the annual throughput are less than 5% (Lodewijks et al., 2009a).

For terminals, where reference information has proved the capacities, the data points are filled. Data points where the capacities are estimated do not have a filling.

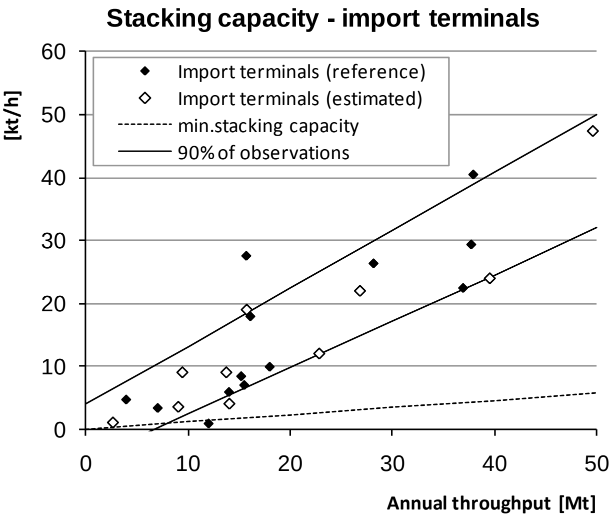

Fig. 12: **Stacking capacity for import terminals**

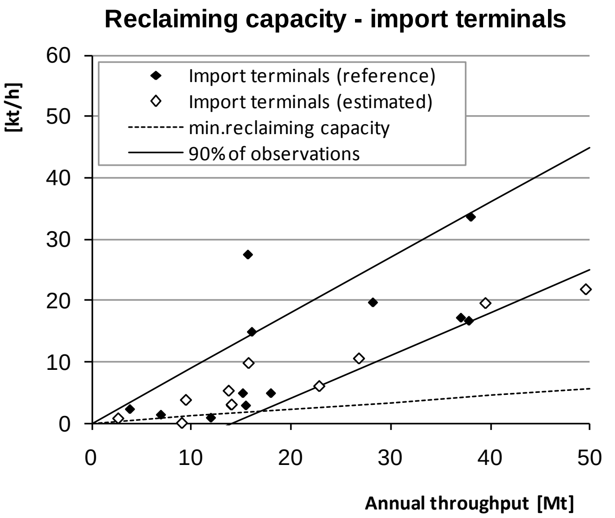

Fig. 13: **Reclaiming capacity for import terminals**

For import terminals, the stacking factor varies between 5.5 and 9. An explanation for these high values is that 70% of the machines at import terminals are combined stacker-reclaimers. These machines have to perform both functions. From figure 13, the reclaiming factor for import terminals can be derived and varies between 4 and 8.

Not all export terminals are represented in figures 14 and 15 because 4 export terminals are not equipped with stackers and reclaimers. From figures 14 and 15, the stacking and reclaiming factors for export terminals can be derived and the stacking factor varies between 3 and 4.5. The reclaiming factor for export terminals varies between 2 and 3.

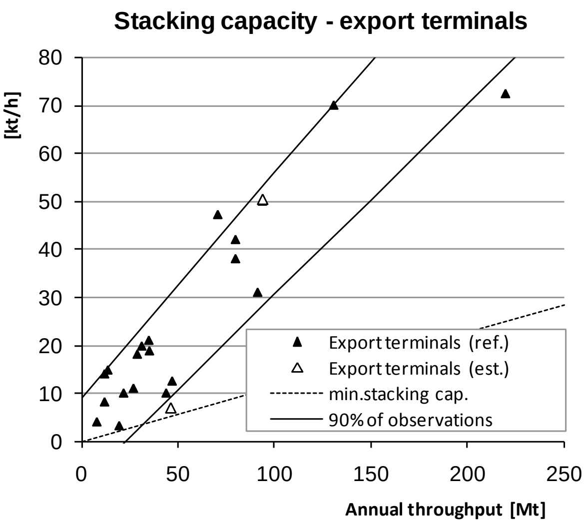

Fig. 14: **Stacking capacity for export terminals**

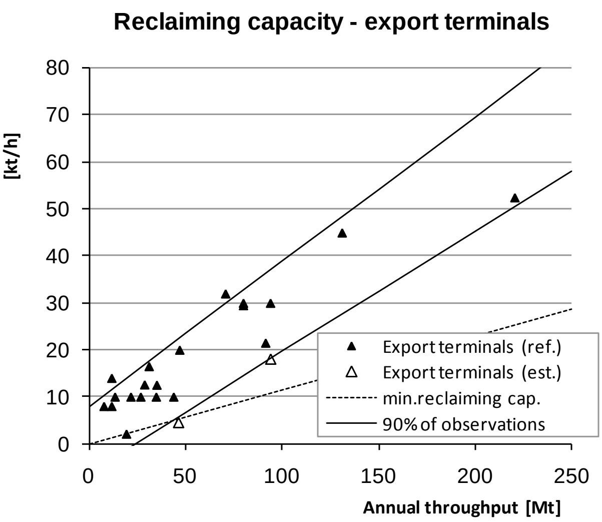

Fig. 15: **Reclaiming capacity for export terminals**

The average stacking and reclaiming capacities for import and export terminals is determined by the average value between the limits of the 90% of observations of figures 12 to 15. If these average capacities are compared with each other, it proves that the installed capacity for import terminals is twice as high as for export terminals to handle the same annual throughput.

5 HINTERLAND SIDE

Depending on the type of a dry bulk terminal, bulk materials are imported to or exported from the terminal area. For the input of the bulk materials at an export terminal, train unloading systems are common, although the Indonesian Pulau Laut Coal Terminal and the Indian Mormugao Port are exclusively fed with barges. A rule of thumb for the maximum turnaround time for trains at a terminal is 4 hours (McCartney, 1996).

Figure 16 shows the loading capacities of the import terminals, the minimum loading capacity and the limits of 90% of the observations. For the terminals, where reference information has proved the output capacities, the data points are filled. Data points where the capacities are estimated do not have a filling.

Figure 16 shows more loading capacity is installed than theoretically necessary. The hinterland loading factor varies between 2 and 5. From figure 17 the hinterland unloading factors can be derived and varies between 1.1 and 3.

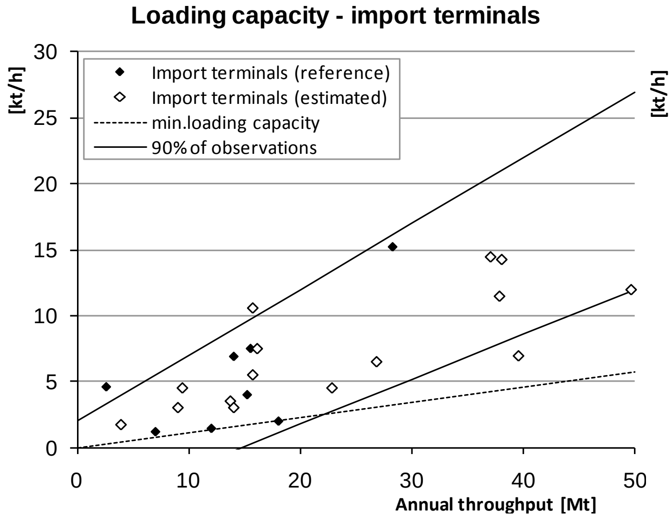

Fig. 16: Loading capacities of import terminals

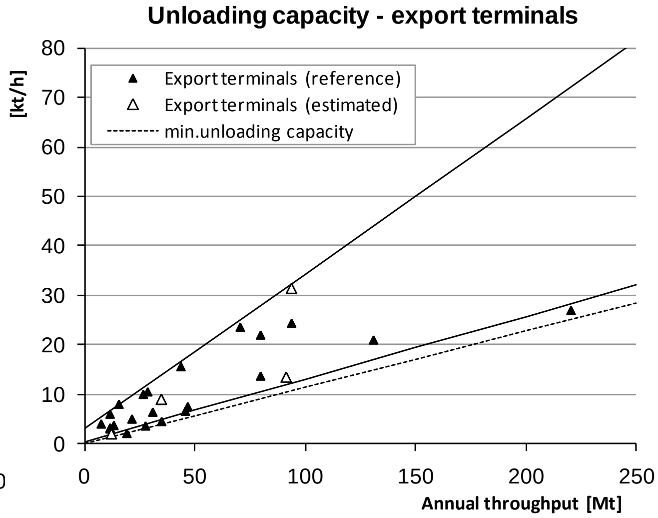

Fig. 17: Unloading capacities of export terminals

6 CONCLUSIONS AND FUTURE WORK

In the previous sections the equipment capacities factors and several characteristics are derived. Table 2 summarizes the capacities factors and table 3 shows the derived terminal characteristics.

Table 2: Capacities factors

Unit: [-]	Import terminals	Export terminals
Seaside (un)loading	3 - 4.5	1.5 - 2.5
Stacking	5.5 - 9	3 - 4.5
Reclaiming	4 - 8	2 - 3
Hinterland (un)loading	2 - 5	1.1 - 3

The capacity factors may be used as guides for calculating the required capacities of terminal designs or expansions. The minimum required capacity can be derived from the division of the required annual throughput and the total operating hours per year. Multiplying this value with the capacity factors of table 2, results in the determination of the required equipment capacities. To prevent an excessive turnaround time of the bulk carriers and trains, the stockyard capacities must be larger than the unloading and loading capacities. The seaside capacities must also be larger than the capacities of the hinterland side.

At import terminals the installed stacking and reclaiming capacity is twice as high as at export terminals to handle the same annual throughput.

Table 3: Terminal characteristics

	Import terminals		Export terminals	
	Coal	Iron Ore	Coal	Iron ore
Quay length factor [kt/m]	10 - 30		25 – 75	50 - 150
Storage factor [t/m^2]	15 - 75	45 - 80	60 - 185	70 - 210
Storage capacity [%]	5 - 22		3 - 10	

The literature rules of thumb match poorly with the derived terminal characteristics of the terminals. If the terminal characteristics are used for terminal design, the designs may vary significantly considering the large range of the characteristics.

To determine more accurate designs, future work will focus on the development of intelligent procedures and algorithms for the operational and logistic control of terminals. The following aspects will be examined; the required number of the machines, the type of machine (for example separate stackers and reclaimers or combined stacker/reclaimers), the optimal routing of the conveyors, the optimal storage locations of the different materials, the terminal layout, the equipment reliability and several operational control methods.

The project finally has to result in a generic approach and software tools for the design, simulation and control of dry bulk terminals.

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