Introducing a Method for More Precise Prediction of Berth Occupancy Ratio in Bulk Liquid Terminals

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ARTICLE INFO	ABSTRACT
	Existing methods presented in references and standards for calculation of berth occupancy ratio, are more concentrated on container terminals. However, some empirical formulas can be found to predict the berth occupancy, but these methods are neither accurate enough nor economically wise to be employed for the prediction of berth occupancy ratio in large and complex bulk liquid terminals. Therefore, it is attempted in this paper to introduce a method for more precise prediction of berth occupancy ratio for bulk liquid terminals. In the proposed method for calculation of berth occupancy ratio in bulk liquid terminals, times which is not used for loading/unloading operation is investigated. The loading/unloading lost factor is considered in calculations in order to calculate the operational value for loading/unloading rate. Next, practical values for these items are given based on previous authors' experiences. Finally, a case study is performed for a liquid bulk petrochemical terminal to specify the presented method. Results show 24% difference between new method and old empirical formulas.

1. Introduction

Occupancy ratio plays an important role in port planning and port master plan design. The number of berths should be established based on operational requirements, driven primarily by berth occupancy considerations. The optimum berth occupancy depends on throughput requirements and site constraints. The assessment of the berth occupancy is based on the consideration of vessel arrival and departure times, time at berth or vessel turnaround time, downtime caused by maintenance, and severe environmental conditions (stopping of loading and/or vessel leaving the berth) (1). Vessel turnaround time is the duration of vessel's stay afloat alongside berth and also viewed as port's operational indicator for its optimum performance in term of the capability, efficiency, and productivity of operation processes of petroleum terminal in handling inbound and outbound cargoes via public liquid-bulk jetties (2). Estimation of vessel (or container group per ship) turnaround time during the considered time period depends on the acceptable average waiting time to average service time ratio. This parameter is obtained as the function of berth occupancy, number of berths, number of containers, waiting and service times and berthing and unberthing times (3).

Various methods and approaches are presented in references and standards for definition of berth occupancy ratio. For example, this ratio is presented in PIANC mainly in term of yearly working times that results an average value of occupancy ratio in a year (4). Carl A. Thoresen, 2003 (5) defines this ratio in term of weekly working and service hours which may results various values for seasons and every month in a year. In addition to design stage and port planning, occupancy ratio is used to evaluate in service port performance in order to planning and performance optimization purpose.

Berth occupancy studies help the designers to plan a terminal in optimum throughput, traffic condition and ship waiting time. Low value of berth occupancy ratio is not acceptable to the port authority from economically point of view, while the high value lead to traffic congestion and increase of ship waiting time. The optimum range of 30-90 (4) and 40-70 (6) percent are given in terms of number of berth and cargo type (container, bulk and liquid bulk) in the related standards.

Generally, berth occupancy ratio shows the port service level which can be defined as bellow:
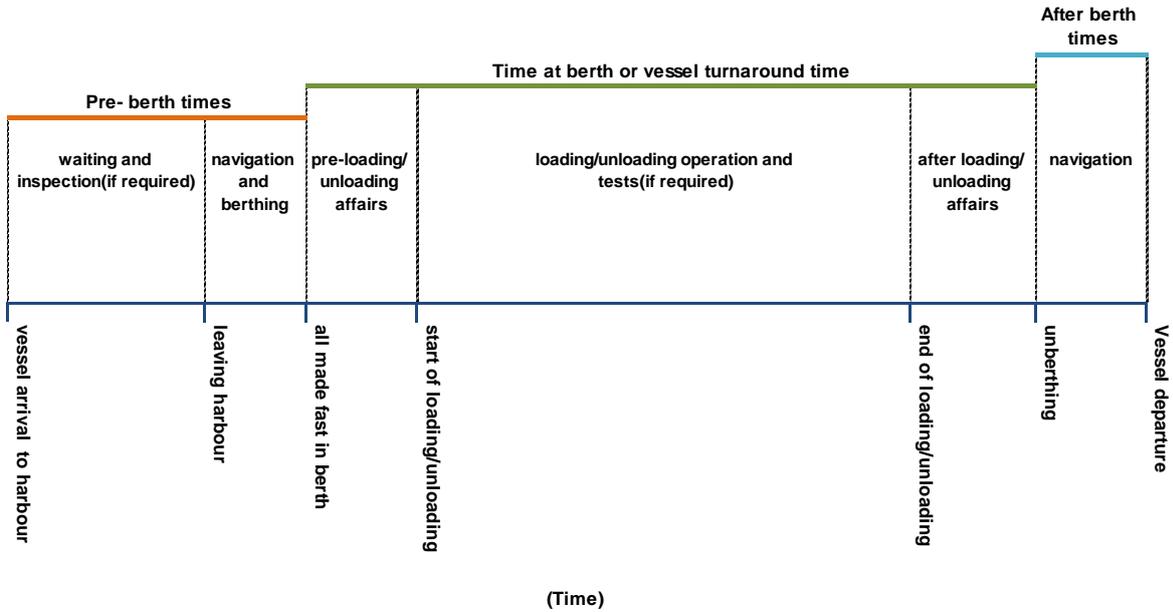
(Time)
Figure 1- Break down of ship's times in port

$$BOR = \frac{T_o}{T_t} \times 100 \qquad (1)$$

BOR Berth Occupancy Ratio in percent

T_o Total time which quay wall is occupied from berthing to un-berthing (vessel turnaround time) in hour in the proposed time span [1]

T_t Total time which quay wall is able to service in hour in the proposed time span (working times)

The value of 365 working days in a year and 24 working hours in a day are common in calculation of yearly working times of modern terminals. This value may be reduced for terminals with low traffic. However calculation of total time which quays are able to service in hour in year (T_t) doesn't need complicated calculations, many items affect calculation of total time which quay walls are occupied (T_o) and needs various considerations in case of port type and performance.

Total times of a ship in a port from arriving to leaving time could be divided to three main time span: pre-berth, at berth and after berth times which are presented in Figure 1.

Pre berth times are related to vessel waiting times, inspection (mainly for bulk cargo ships) and vessel navigation from harbor to berth and berthing operation times. At berth times (T_o in Equation 1) are mainly related to loading/unloading operation. The affairs related to meetings, documentation and inspections have fewer shares in this time span which are grouped as pre and after loading affairs. Finally, after berth times which are related to vessel navigation from berth to sea. However, the details of each time

span are different for various terminals (container, bulk, general cargo) and may vary due to port performance, the presented structure in Figure 1 is fixed.

1. **2. Calculation of total time which quay walls are occupied (T_o)**

In case of investigation of berth occupancy ratio in actual operational condition (previous port performance), T_o may be calculated based on registered times in ships' statement of fact documents for the proposed timespan which is calculated as below for each berth separately:

$$T_0 = \sum_{i=1}^{n} (T_{Unberthed} - T_{Allmadefast})_i \qquad (2)$$

$T_{Unberthed}$ The registered time in ship's statement of fact do cuments that ship is unberthed from the quay (hour).

$T_{Allmadefast}$ The registered time in ship's statement of fact documents that berthing works are finished and ship is ready for inspection and loading/unloading (hour).

i Total number of ship which is berthed in the proposed berth for the proposed time span.

In case of investigating berth occupancy ratio for port planning, The ratio of port yearly throughput to port loading/unloading capacity results an estimate for T_o (equation 3).

$$T_o = \frac{A.T.}{P} \qquad (3)$$

A.T. Berth annual planned throughput in TEU or ton per year

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1 One week, month or year which is selected based on port traffic and available data. For ports with very high traffic, period of one week is adequate. In present paper, the timespan of a year was considered for calculations.

P The berth's equipment productivity in ton or TEU per hour

For more exact calculation of T_o, various parameters which affect loading/unloading operation should be applied to equation 3. Times of berthing which is not used for loading/unloading operation like documentations and clearance, inspections and meetings are neglected in this method. In the following, T_o is investigated in two parts. First, times for loading/unloading operation and second, times for tank inspection and sampling, documentation and clearance. As performance system and timing are different for container, dry bulk and bulk liquid terminals, calculation of T_o is presented for each terminal separately.

2.1. Container Terminals

The investigation of container terminals in respect to BOR is completely different with other terminals and mainly affected by productivity of each meter of quay wall length, which is estimated by crane density in quay wall and crane productivity. These numbers vary in term of berth design vessel and loading/unloading equipment. The average value of crane density is one crane per 100 m of quay wall and in modern container terminals is about one crane per 75 m. The crane productivity varies from 10 lift/hour for mobile harbor cranes to 30 lift/hour for modern ship to shore gantry cranes (4). So, T_o in container terminals can be calculated as presented in below equation:

$$T_o = \frac{A.T.}{N_c \times P_B \times f_{TEU}} + N_s \times T_{other} \qquad (4)$$

$A.T.$ Terminal annual planned throughput in TEU per year

N_c Number of crane in terminal or berth

P_C The berth's crane productivity in lift/hour

f_{TEU} The ratio of 20 ft. containers compared to 40 ft. containers (TEU/Box), which may be considered about 1.5.

N_s Total number of ship in a berth for year.

T_{other} Times which are related to inspections, documentation and clearance in hour which should be calculated based on port performance.

2.2. Dry Bulk Terminals

As cargo type and loading/unloading capacity of equipment may vary in each berth of a bulk terminal (liquid/dry), the occupancy ratio calculation for these ports should be investigated for each berth or berths with the same cargo type and loading/unloading equipment separately. So, the relation for T_o is given as below in term of annual throughput and number of ship in year:

$$T_o = \frac{A.T.}{P_B} + N_s \times T_{other} \qquad (5)$$

$A.T.$ Berth annual throughput in ton per year

P_B The berth's equipment productivity in ton/hour

N_s Total number of ship in a berth for year.

T_{other} Times which are related to hold inspection, draft survey and documentation and clearance which should be calculated based on port performance.

Ratio of the cargo(s) annual throughput to design vessel capacity results total number of ship for berth in a year. For more exact results, an average size for vessels or even proposed cargo parcel size is used instead of design vessel capacity. In some cases, there are two or more cargo loading/unloading equipment in one berth which may be for the same or various cargo types. In case of same cargo, the total value of equipment productivity should be used in equation 5 and In case of various cargo types, T_o should be investigated for each cargo separately and the sum of calculated times are used for calculation of occupancy ratio. So for the second case, equation 5 can be write as bellow:

$$T_o = \sum_{i=1}^{m} (\frac{A.T.}{P_B} + N_s \times T_{other})_i \qquad (6)$$

$A.T., P_B, N_s, T_{other}$ Reefer to equation 5

i Number of cargo types in one berth

2.3. Bulk Liquid Terminals

The formula for bulk liquid terminals is like dry bulk terminals but product density and loading/unloading lost factor should be considered in calculations. So, the equation 5 is rewritten as below:

$$T_o = \frac{A.T.}{P_B \times f_L \times \rho} + N_S T_{other} \qquad (7)$$

$A.T.$ Berth annual throughput in ton per year

P_B The berth's equipment productivity or nominal pumping rate in cubic meter/hour which is given for loading arm or hose

ρ Product density in ton/cubic meter

f_L Loading/unloading lost factor

N_s Total number of ship in a berth for year.

T_{other} Times which are related to hold inspection, draft survey and documentation and clearance in hour which should be calculated based on port performance.

In bulk liquid terminals the operational value for berth's equipment productivity is not the same

nominal values mainly due to product evaporation (for liquid gas products), pump performance and due to line blowing after loading completion. So, the loading/unloading lost factor is applied here for more exact results. The below equation is given to calculate lost factor for each product or product with the same specification:

$$f_L = \frac{\sum_{i=1}^{q}(\frac{P.S.}{P_B \times \rho \times T_{L/U}})_i}{q} \tag{8}$$

f_L, P_B, ρ Reefer to equation 7

$P.S.$ Cargo parcel size in ton which was loaded/unloaded

$T_{L/U}$ Practical time for loading/unloading time based on port performance (ships' statement of fact document)

i Number of investigated operations for one product

The value of lost factor is various for liquid and gas products and ever may changes for various products by density.

Product handling in bulk liquid terminal with high value of annual throughput like oil terminals is performed by more than one loading arm or hose. In this case, the total value of equipment productivity (P_B) should be used in equation 7. As each berth in refined or white products (Petrochemicals) performed loading/unloading of various products, calculation of T_o should be performed for each product separately as presented in equation 9.

$$T_o = \sum_{i=1}^{m}(\frac{A.T.}{P_B \times f_L \times \rho} + N_s \times T_{other})_i \tag{9}$$

$A.T.$, P_B, f_L,   Reefer to equation 7

ρ, N_s, T_{other}

i Number of cargo types in one berth

Considering all parameters for calculation of T_o in bulk liquid terminals, equation 10 is given for calculation of berth occupancy ratio in bulk liquid terminals.

$$BOR = \frac{\sum_{i=1}^{m}(\frac{A.T.}{P_B \times f_L \times \rho} + N_s \times T_{other})_i}{T_t} \times 100 \tag{10}$$

BOR Reefer to equation 1

$A.T.$, P_B, f_L, ρ, N_s, T_{other} Reefer to equation 7

i Reefer to equation 9

Parameters like loading/unloading lost factor and times which are not usable for loading/unloading operation have been applied in equation 3 to reach more exact results for T_o. It is clear that berth occupancy ratio is generally affected by berth's equipment productivity and terminal working hours, but the presented parameters may change the result considerably. To clarify the difference of results for each method, In the next section a case study is performed for calculation of berth occupancy ratio in a bulk liquid petrochemical terminal.

3. Case Study-Occupancy Ratio in a Bulk liquid terminal

In this section, a case study has been performed in one berth of a petrochemical terminal. The proposed berth performs loading/unloading of 9 product with 8 loading/unloading equipment as shown in Figure 2.
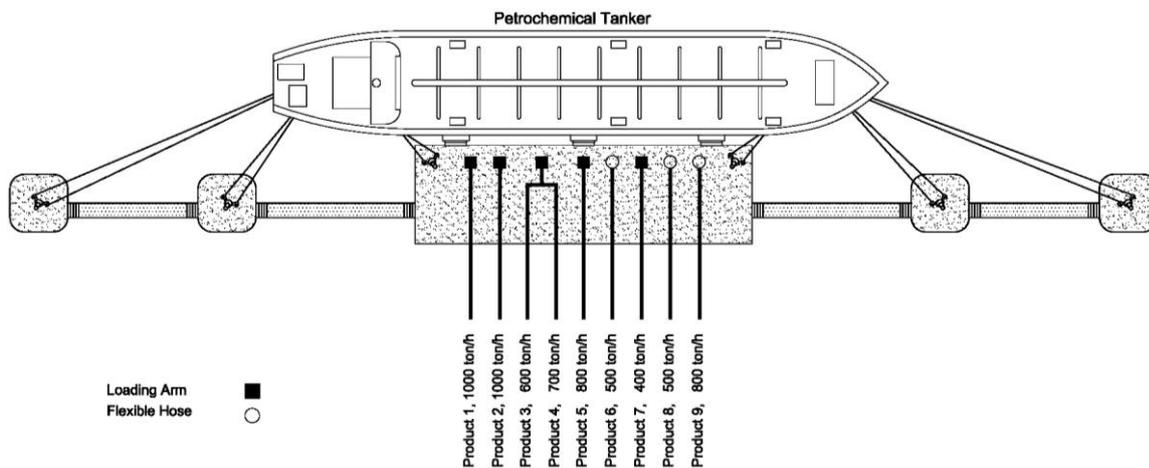

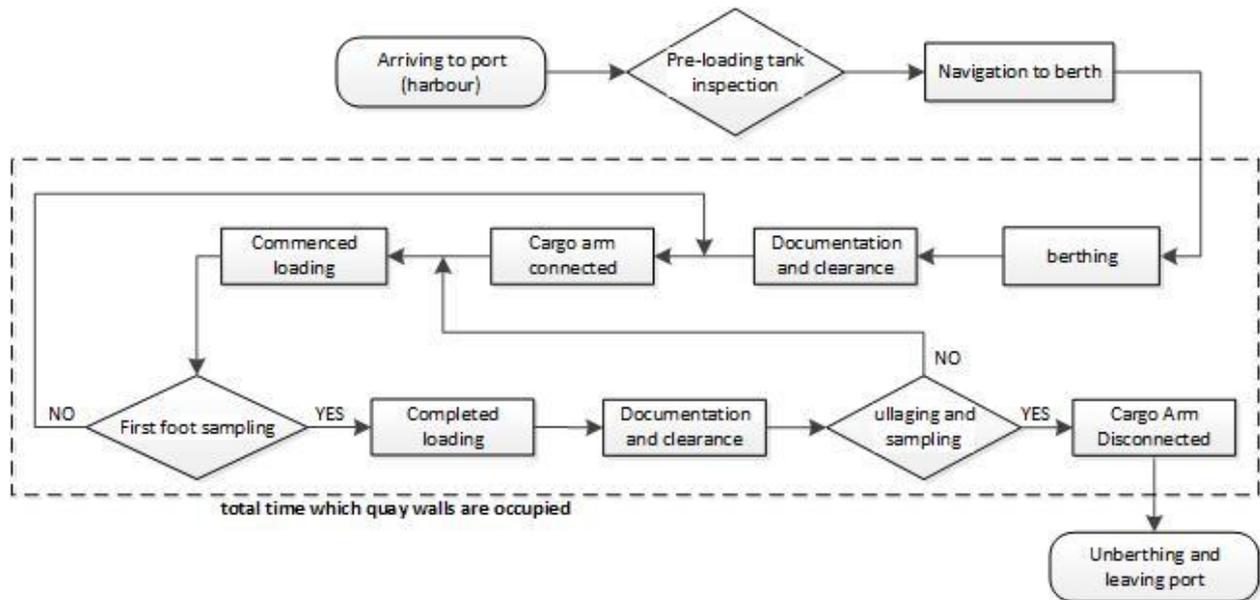**Figure 2-Berth Product Block Diagram**

Figure 3.The port performance process diagram (export operation)

Table 1. List of products and occupancy ratio calculations

Yearly Troghput (ton/year)	Parcel Size (ton)	Number of Ship in Year	Loading/Unloading Equipment	Nominal Pumping Rate (cbm/hour)	f_L	Pumping Time in Hours	T_{other}	T_o	T_o by Equation 3
540,000	15,000	36	Loading Arm	1000	70%	957.1	144	1,065.1	670.0
430,000	12,000	36	Loading Arm	1000	70%	902.0	144	1,010.0	631.4
370,000	10,000	37	Loading Arm	600	70%	998.8	148	1,109.8	699.2
220,000	10,000	22		700	70%	567.6	88	633.6	397.3
320,000	10,000	32	Loading Arm	800	70%	930.7	128	1,026.7	651.5
110,000	8,000	14	Hose	500	70%	329.0	56	371.0	368.5
85,000	8,000	11	Loading Arm	400	70%	159.8	44	192.8	139.8
55,000	15,000	4	Hose	500	70%	231.1	16	243.1	129.4
38,000	10,000	4	Hose	800	70%	174.0	16	186.0	76.1
2,168,000.0							Total	5,838	3,763
							T_t	8,760	8,760
							Occupancy Ratio	67%	43%

Before investigation of berth occupancy ratio in a terminal, it is necessary to analyze ship's times in the port from arriving to leaving. Details of these times are presented in Figure 1, should be specified for the proposed investigated port. It could be more applicable if the breakdown be studied along with port performance process diagram. The port performance process diagram for the proposed port is presented in Figure 3. Port performance process diagram directly affects berth occupancy ratio and shall be analyzed before berth occupancy ratio calculation. In some cases, optimization in this diagram may reduce berth occupancy ratio. For example, in some bulk liquid terminals, pre-loading tank inspections are performed in berth which increases ship's times at berth and berth occupancy ratio. But in the investigated port these tests are performed in harbor (pre-berth times)

that reduces ship's times at berth and berth occupancy ratio. Parts which are related to ship's at berth times are separated in The port performance process diagram (Figure 3).

The yearly throughput of each product is shown in the

Table 1. The total berth throughput is 2.168 million ton per year. The number of ships in a year are calculated from division of yearly throughput to average cargo parcel sizes for each product separately. Considering port performance process diagram and ship's time breakdown, The value of 3 hour[2] is calculated for T_{other} (equation 7). The next-to-last column is total time which quay walls are occupied (T_o based on equation 9). The average value of 70% is

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[2] As mentioned in section 3.2 the value for this parameter should be investigated for the proposed terminal. The value between 2-4 hour is common in practical.

considered for loading/unloading lost factor in the investigated berth. As given in the last row of table 1, the berth was occupied for 5,838 hours in a year. Considering 365 working days in a year and 24 working hours in a day, T_t is 8760 hours for this berth (for a year). So, the occupancy ratio for the berth is 67% based on equation 1. In the last column total time which quay walls are occupied (T_o) was given with the general equation for calculation of this number (equation 3) and the value of 43% was calculated for occupancy ratio which has about 24% difference with the new proposed method.

4. Conclusion

Calculation of berth occupancy ratio are investigated for container, dry bulk and bulk liquid terminals in present study. Considering various parameter in bulk liquid terminals, a method for more precise prediction of berth occupancy ratio has been introduced for these terminals. However, berth occupancy ratio is generally affected by berth's equipment productivity and terminal working hours, other factors like loading/unloading lost factor and times which are not usable for loading/unloading should be considered in bulk liquid terminals. Finally, to clarify the proposed method, a case study was performed in a bulk liquid terminal. The impact of 24% was observed for considering of loading/unloading lost factor and times which are not usable for loading/unloading in calculation of berth occupancy ratio for the terminal.

5. References

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