OPERATIONAL CONTROL FOR STACKER/RECLAIMERS

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ABSTRACT

At dry bulk terminals, combined machines for stacking and reclaiming (stacker/reclaimers) are generally installed to handle the incoming as well as the outgoing flow of bulk materials. At the seaside of an import dry bulk terminal, large bulk carriers are unloaded while at the landside trains or barges are loaded. During unloading and stacking of the bulk materials a stacker/reclaimer is occupied for a long time. When trains or barges arrive during that time, they may have to wait a long time before getting loaded. The operational control of an import terminal can be improved by interrupting the ship unloading and load trains or barges in between. With the proposed simulation-based approach, the effect of this change in operational control was investigated. Trains or barges can be loaded significantly quicker still guaranteeing the agreed seaside service rate.

Keywords: dry bulk terminal, operational control, discrete-event simulation, service rate

1. INTRODUCTION

Dry bulk terminals are essential nodes in the major transportation links for coal and iron ore. These bulk materials are used for the worldwide production of energy and steel. This paper focuses on import terminals where bulk materials are imported at the seaside and exported at the landside. The operation at export terminals is comparable but the direction of the bulk materials flow is opposite. An import dry bulk terminal consists of (i) a seaside where bulk carriers are moored to be unloaded, (ii) a stockyard equipped with stockyard machines for the temporary storage of the bulk materials and (iii) a landside where trains or barges are loaded. In Figure 1 an example of an import terminal in Rotterdam is shown at the time when one of the largest bulk carriers in the world arrived at the terminal's seaside.

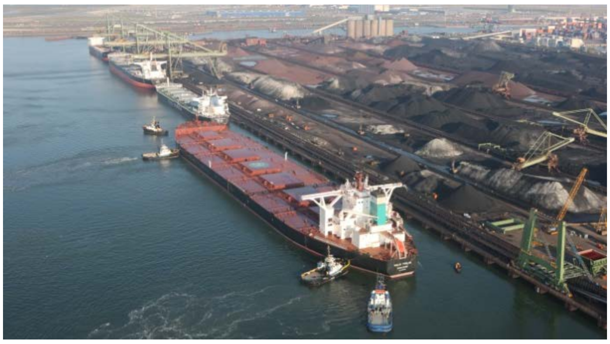

Figure 1: A dry bulk terminal (Courtesy of EMO BV)

Generally, at import terminals stacker/reclaimers are used. These machines combine the two functions of stacking and reclaiming into a single unit. Consequently one of the two functions can be fulfilled at a time. Figure 2 shows a bucket wheel stacker/reclaimer during stacking of coal. For reclaiming, the bucket wheel, at the end of the machine's boom, digs the material from the pile and dumps it onto the boom conveyor. The material is transported through the machine, dumped on a yard conveyor and transported to its new destination.

Figure 2: Bucket wheel stacker/reclaimer (Courtesy of ThyssenKrupp)

The seaside and landside transport modalities vary considerably in sizes. Bulk carriers can contain more than 350,000 tons (like the arriving bulk carrier of Figure 1) but the average train load, in for example Western Europe, is limited to 4,000 tons. During the unloading of one bulk carrier, many trains arrive at the terminal's landside. If the stacker/reclaimer continues unloading a bulk carrier and at the same time trains request material which is stored in the reach of this active stacker/reclaimer, trains have to wait before being loaded. Excessive waiting of trains leads to an unsatisfactory service to the train operators and cargo owners. Interrupting the ship unloading and handling trains in between can be a solution. However, serving the bulk carrier cannot be interrupted infinitely because terminal operators have limited time to unload ships.

The terminal performance can be expressed in the seaside and landside service rates. The seaside service rate is generally agreed between terminal operators and ship-owners and indicates the maximum time that a ship may spend in the port. The seaside service rate is calculated by dividing the ships load by the total time that this ship spends at the terminal. The total time is the sum of the waiting and the unloading time. For the landside service rate, it is less common that this rate is agreed on beforehand but the quicker a train or barge is served the better.

This paper assesses two different operational procedures for stacker/reclaimers.

2. OPERATIONAL PROCEDURES

Stacker/reclaimers handle bulk materials which are stored in piles at the stockyard lanes parallel to the machine's belt conveyor. Figure 3 shows a fictive situation where bulk materials are stored in lanes parallel to the stacker/reclaimer. A bulk carrier filled with grade B is unloaded and these materials are stacked by the stacker/reclaimer. During stacking, a train arrives which must be loaded with grade D. The stacker/reclaimer has now two options. The first one is to continue unloading and let the train wait. The second one is to interrupt the stacking action, and so the ship unloading, travels to pile D and reclaims the bulk materials which can be loaded in the railcars. When the railcars are filled, the stacker/reclaimer can continue stacking the materials out of the bulk carrier.

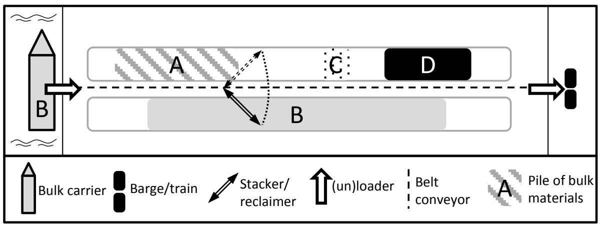

Figure 3: Situation sketch

The first option is called the FIFO (First In, First Out) operational procedure. Based on the order of arriving, the first job is served completely without any interruption, no matter if this is a bulk carrier or train. Figure 4A shows this procedure schematically; the arrival sequence determines which job is served.

The second option is called the FIFO+ operational procedure, which is displayed in Figure 4B. The order of arrivals still determines the order of the served jobs. However, if during ship serving a barge or train arrives and the bulk carrier has enough time left, this landside job is served in between. Figure 4B shows an arbitrary situation that during unloading of a bulk carrier, three arriving barge/trains are loaded. The intended advantage is that the landside service rate will be increased because the barges or trains have to wait shorter.

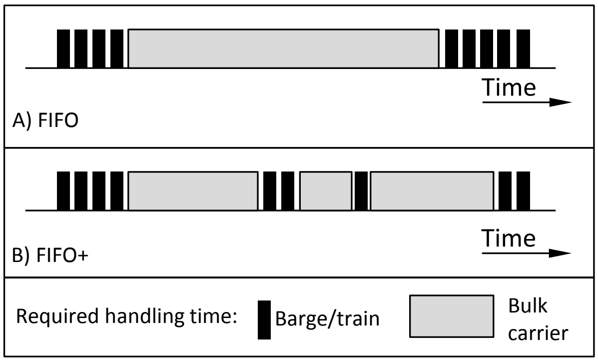

Figure 4: Two different operational procedures

For the comparison of the two operational procedures it was assumed that (i) the (un)loaders and the belt conveyor have the same handling capacity as the stacker/reclaimer, (ii) there is always area available to store the incoming material, (iii) the requested bulk material at the landside is always available and (iv) the needed travelling time of the stacker/reclaimer is not considered.

Besides, the following preconditions for the FIFO+ operational procedure were defined:

1. The handling of landside jobs during bulk carrier unloading is only performed if there are no bulk carriers waiting.
2. There is no time lost for switching between seaside and landside jobs.

3. SIMULATION-BASED APPROACH

Both operational procedures have to be judged by comparing the seaside and landside service rates. For the analytical derivation, queuing theory formulas look promising. However, previous research showed that the machine's service time distribution cannot be represented with a general distribution (Van Vianen, Ottjes and Lodewijks 2012). Furthermore, interrupting a job and continuing with another one cannot be regarded using queuing formulas.

That's why a simulation-based approach is proposed. For modeling the stacker/reclaimer activities the process-interaction method was used. This method was introduced by (Zeigler, Praehofer and Kim 2000; Fishmann 2001; Veeke and Ottjes 1999). In this approach the system is virtually broken down into relevant element classes each with their typical attributes, which results in an object oriented data structure of the system. For all active element classes process descriptions, which describe the functioning of this element as a function of time, have to be defined. The last step is to create all necessary elements according to their classes and start the processes of these elements. In the simulation model all active elements act parallel in time, synchronized by the sequencing mechanism of the simulation software (Ottjes and Lodewijks 2004).

The simulation model is built in Delphi and TOMAS (which is an abbreviation for Tool for Object oriented Modeling And Simulation) is implemented as a toolbox in the application-development environment of Delphi. (TOMAS can be downloaded for free from www.tomasweb.nl). Generally, a seaside job generator was used to create the arriving of bulk carriers and a landside generator generates the landside jobs. Both jobs were handled by the predefined simulation element stacker/reclaimer. Details for the job generators are presented in section 3.1 and a description for the stacker/reclaimer is shown in section 3.2.

3.1. Job Generators

Two job generators were created, one for the seaside and one for the landside jobs. Table 1 shows the attributes, the process and an algorithm (CheckTime) for the landside job generator. The 'CheckTime' algorithm checks if the current unloaded ship has time left to be interrupted for loading a landside job in between. The process for the seaside job generator is not shown in this paper but is comparable to Table 1.

Input files (SeaFile and LandFile) were used as input for the job generators for the jobs arrival times, loads and grades. These input files have to be composed separately and can be based on historical data or, when historical data is unavailable, be derived from stochastic distributions.

A job is created after waiting the interarrival time between two jobs. For the FIFO procedure a new job is directly putted in the JobQ and in the LandsideQ. If the FIFO+ operational procedure is activated and the stacker/reclaimer is idle, this landside job can directly be served and is therefore directly placed in the JobQ as well. For FIFO+, the algorithm CheckTime is activated when the stacker/reclaimer is active at the moment that the landside job is created.

In the function CheckTime is first determined if there is already a waiting ship. If there is a bulk carrier waiting, the result of this function is 'No SR Available' according precondition 1 of section 2. If there is no new ship waiting, the available time of the current served ship will be calculated using the following relation:

$$t = t_m - \left(W_t + W_s + W_{s\_req} + W_i\right) \qquad (1)$$

Where t is the job's available time [h], t_m is the maximum time that this ship may spend in the port [h] (which can be calculated by dividing the job's load with the agreed minimum service rate), W_t is the time that this ship already waited before getting unloaded [h], W_s is the total service time till now [h], W_{s_req} is the required service time to finish this job [h] and W_i is the ship's total interrupted time [h].

If the available time (t) exceeds the required time to serve the landside job, the stacker/reclaimer can be used. The stacker/reclaimer is then interrupted, the current ship is defined as the previous job and its remaining load is calculated. The stacker/reclaimer starts serving the landside job. If there is no available time left, the landside job cannot be served directly and has to wait in the JobQ.

Table 1: Landside Job Generator

Attributes MyJob: JobClass, MyFile: TomasFile, Process: Procedure, CheckTime: function, t: double (available time)
Process MyFile = LandFile Read input (T_A, tons, grade) from MyFile Wait Interarrival time between two successive arrivals MyJob=JobClass.Create and add attributes MyTons and MaxTime If FIFO or FIFO+ and SR is idle then MyJob.EnterQueue(JobQ & LandSideQ) else FindSR If 'SR Available' then • stop this SR, define the new job of SR as MyJob and define the SR's previous job (SJob) • calculate the remaining tons of the previous job • restart SR If 'No SR Available' then MyJob.EnterQueue(JobQ & LandSideQ)
CheckTime If there is a SJob in SeaSideQ then result = 'No SR Available' If SeaSideQ is empty and SR handles a SJob then • determine SR.MyJob.t_m, SR.MyJob.W_t, SR.MyJob.W_s, SR.MyJob.W_i, SR.MyJob.W_{s_req} • calculate t based on equation (1) • if t – (MyJob.MyTons / MySR.ReclaimCap) >= 0 then result = 'SR Available' • if t – (MyJob.MyTons / MySR.ReclaimCap) < 0 then result = 'No SR Available'

The seaside job generator differs from the discussed landside job generator because seaside jobs are always directly putted in the JobQ and in the SeaSideQ.

Table 1 shows that the common object oriented dot notation was used for qualifying methods and properties to the main elements of the simulation model. So for example MyJob•MyTons means the amount of tons of this job and MyJob=JobClass•Create causes creation of an instance of the job class.

3.2. Stacker/Reclaimer

For the stacker/reclaimer a specific element class was defined which contains a process and a function SelectJob. Table 2 shows details for this element. The function SelectJob is activated when the stacker/reclaimer has finished a job. When the machine had already worked on an interrupted job and there is a ship waiting, the stacker/reclaimer will continue serving this ship (which was defined by the landside job generator as previous job). When the interrupted job leaves enough time to handle a landside job in between, there are only trains waiting, a train can probably be served. To check if material for a train is stored in the reach of a stacker/reclaimer, this machine has a specific queue, MyGradesQ. In this queue the accessible grades are listed. If the grade of this job corresponds with one of the grades stored in MyGradesQ, this job will be selected to be served.

In the stacker/reclaimer process, the selected job will be moved from the right queues and the job's handling time (t_h) will be calculated based on the job's load and the machine's capacity. After the handling time the job is finished and erased from the system.

Table 2: Stacker/Reclaimer Class

Attributes MyJob : JobClass, PrevJob: JobClass (previous job but interrupted during serving), StackCap, ReclaimCap: double, SelectJob = function, t_s: double (handling time)
Process Repeat While there is no Job to handle: standby (SelectJob: 'No Job') If Result = Seaside Job then MyJob.LeaveQueue(WSQ) else MyJob.LeaveQueue(LSQ) MyJob.LeaveQueue(JobQ) If Result = Seaside Job then t_h=MyJob.Mytons / StackCap else t_h=MyJob.Mytons / ReclaimCap Wait during t_h MyJob.Destroy

SelectJob
If (no assigned MyJob but there is an assigned PrevJob) and (no time available anymore of the PrevJob ór there is a ship waiting) then Result= PrevJob
Else MyJob=JobQ.FirstElement
Begin
If MyJob.MyGrade.IsInQueue(MyGradesQ) then Result = MyJob
If NOT MyJob.MyGrade.IsInQueue(MyGradesQ) and MyJob is not last element of JobQ then MyJob = successor in JobQ
If NOT MyJob.MyGrade.IsInQueue(MyGradesQ) and MyJob is the last element of JobQ then Result = 'No Job'
end

The simulation model uses three general queues, where elements are stored for the control of the model. In the JobQ, the seajobs and landjobs are stored in the order of arriving. The seaside queue and the landside queue are used to store the seajobs and landjobs respectively when these jobs have to wait before getting served. A simplified representation of the simulation model is shown in Figure 5.

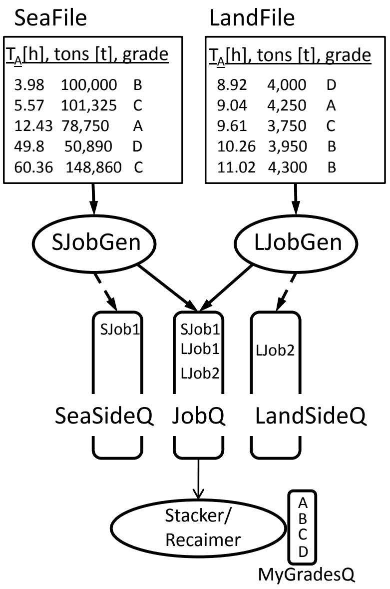

Figure 5: Schematic representation of the simulation model

3.3. Verification and Validation

The simulation model aims to be an accurate representation of a conceptual operational model for using the FIFO or FIFO+ procedures at a dry bulk terminal. According (Kleijnen 1995) verification is required to determine if the simulation model performs as intended. Validation is concerned to determine if the simulation model is an accurate representation of the system under study.

Verification was performed using (i) the tracing function of TOMAS and (ii) comparing the simulation results with analytical results. The average ship's waiting time (W_t) as function of the inverse of the service rate (1/μ) was determined analytically for an M/D/1-queuing system using the Pollaczek–Khinchine mean value formula (which was reformulated by Adan and Resing 2002). The simulation model was also used to determine the average ship's waiting time versus the machine's utilization (ρ) for the same queuing system. Both ships and train arrives according a negative exponential distribution (M), the service times were constant, and one stacker/reclaimer was used with the FIFO operational procedure. Figure 6 shows that the analytical results (M/D/1) correspond with the simulation results, which implies that the model is verified.

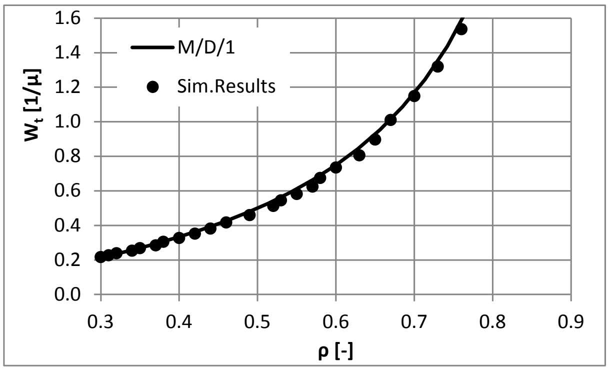

Figure 6: Verification of simulation model

Validation was not possible because there does not exist real data to compare with yet because the system under study is a conceptual model.

4. SIMULATION RESULTS

Both FIFO and FIFO+ operational procedures will be assessed for a specific case by varying the annual throughput per stacker/reclaimer. The annual throughput when the average service rate will fall beneath the minimum required service rate is the maximum annual throughput per machine. It is expected that when the FIFO+ operational procedure will be used, this value can be increased. In section 4.1, the used input parameters will be specified and in section 4.2, the results will be shown.

4.1. Input

To create input files, which comply with daily practice at import terminals, the seaside and the landside processes were investigated for several dry bulk terminals.

4.1.1. Seaside

Previous research showed that the ships interarrival times can be modeled using standardized stochastic distributions (Van Vianen, Ottjes, and Lodewijks 2012).

Depending on the terminal type, a specific distribution type must be selected. For this case, it was assumed that the terminal is a stevedoring import terminal. This terminal has to serve many clients and does hardly have any influence in the arrival times of the ships. The interarrival time distribution can then as best be represented by the negative exponential distribution.

Generally, the carrier tonnage distribution cannot be represented with generalized distribution types. The investigated terminals showed a large variation mainly based on the visiting carrier classes. Historical data of visited ships during three years of operation of a specific terminal was used as input for the ship sizes.

4.1.2. Landside

For this case it was assumed that also the interarrival time distribution of the landside jobs can be represented with a negative exponential distribution. This happens when, for example, trains can be temporarily congested in railway lines or barges can be blocked on the rivers. The arrival process is then not regular anymore. The terminal has to wait for the arrival of trains and barges followed by a close succession of trains and barges.

For the landside it was assumed that the job loads do not vary that much. This assumption corresponds with the historical data of the investigated terminals. A uniform distribution between a minimum (2 [kt]) and a maximum value (4 [kt]) was used to represent the landside size distribution in the LandFile.

In Table 3 the used parameters for the simulation runs are listed.

Table 3: Input Parameters

	Seaside	Landside
Interarrival time distribution	NED	NED
Tonnage distribution	Based on historical data	Uniform
Average tonnage [kt]	101	3
Net machine capacity [kt/h]	2.5	
Minimum required service rate [kt/h]	1.75	

Table 3 lists the minimum required seaside and landside service rate of 1.75 kilotons per hour [kt/h]. This rate corresponds to realistic agreed service rates between import terminal operators and ship-owners. Besides, it was assumed that this rate must also be achieved at the landside to provide acceptable service to train operators and cargo owners. Note that the installed machine capacity has a higher value (2.5 [kt/h]) which allows ship waiting and/or interruption during unloading. The simulation runs were performed using a simulation run time of 25 years to minimize the influence of the stochastic variances of the interarrival time distributions.

4.2. Results

The performance indicators, which will be used for the assessment of both operational procedures are (i) the average seaside and landside service rates (which must at least exceed the predefined service capacity of 1,75 [kt/h]) and (ii) the realized annual throughput.

The average seaside and landside service rates were determined at the end of the simulation run. Figures 7 and 8 show the realized service rates versus the stacker/reclaimer annual throughput for the FIFO procedure (Figure 7) and for the FIFO+ procedure (Figure 8).

For the FIFO operational procedure, the maximum annual throughput for a stacker/reclaimer is 4.6 million tons per year [Mt/y] guaranteeing an average service rates of 1.75 [kt/h].

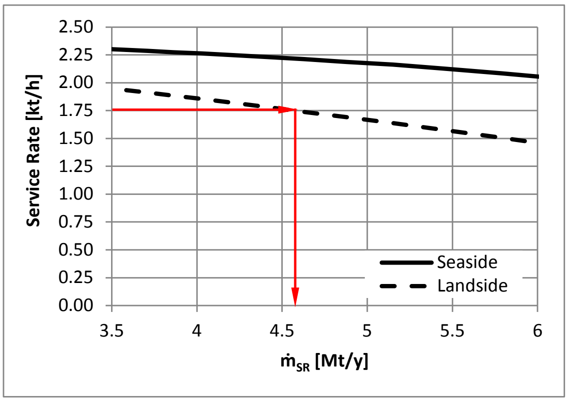

Figure 7: Service rates versus the stacker/reclaimer annual throughput for the FIFO operational procedure

When the FIFO+ operational procedure was used (see for the results in Figure 8), the landside service rate can be increased significantly. Obviously, this leads to a reduction of the seaside service rate. But for an annual throughput until 5.7 [Mt/y], the service rates still exceed the minimum required service rate. From Figure 8 can also be detected that the seaside and landside service rates are in the same range, in contrast to the FIFO procedure.

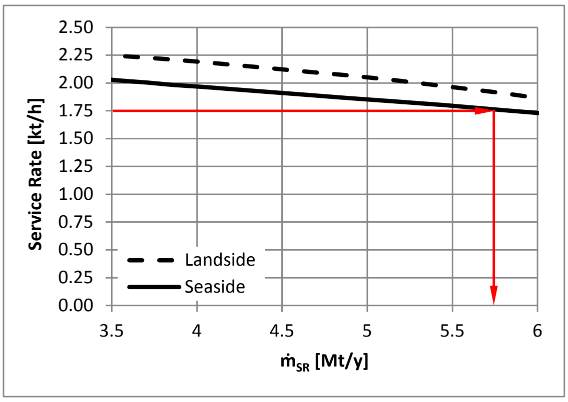

Figure 8: Service rates versus the stacker/reclaimer annual throughput for the FIFO+ operational procedure

Figures 7 and 8 show the realized average service rates for both seaside and landside. To verify if ships are still served when the FIFO+ procedure is used, the service performance was measured. This indicator represents the percentage of ships which do not have to stay longer at the terminal then agreed. Figure 9 shows the performance of served ships for both operational procedures versus the machine's annual throughput. From Figure 9 can be concluded that there is no difference in service performance regarding the used operational procedures. The used algorithm enables the realization of a higher landside service rate without a reduction of the seaside performance. The arrival processes and the installed machine's capacity determine ships waiting and thus the service performance.

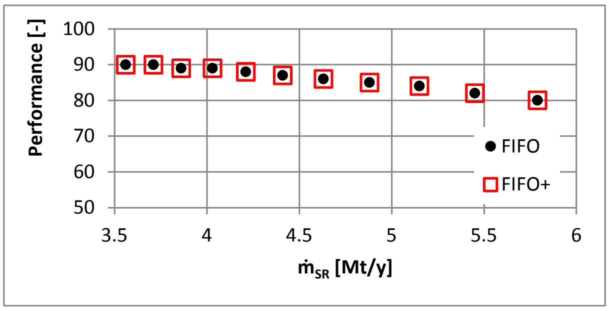

Figure 9: The percentage of ships which were served on time versus the annual throughput

For the FIFO+ operational procedure, the average number of interruptions (N_i) during ship unloading was registered and is shown in Figure 10. As expected, ship unloading will be interrupted more when the annual throughput increased. For the determined annual throughput of 5.7 [Mt/y] (see Figure 8), the unloading process of a bulk carrier is on average 6.5 times interrupted.

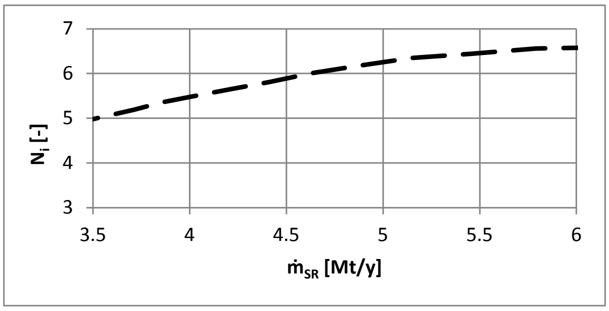

Figure 10: Average number of interruptions during ship unloading for the FIFO+ operational procedure

5. CONCLUSION AND DISCUSSION

The FIFO and the FIFO+ operational procedures for stacker/reclaimers were evaluated. Using the FIFO procedure causes a large variation between the seaside and landside service rates. The maximum annual throughput for the stacker/reclaimer is then limited by the landside service rate while the seaside service rate exceeds the minimum required service rate. The landside service rate can be increased significantly by interrupting ship unloading while still guaranteeing the ship's service rate. This procedure was called FIFO+. Results for a specific case showed that the annual throughput for a stacker/reclaimer can be increased with 24% from 4.6 until 5.7 [Mt/y] while the minimum predefined service rates were still realized. The FIFO+ operational procedure enables terminal operators to serve clients at the landside better which will made these terminals more attractive. However, ship unloading must be interrupted 6.5 times on average per bulk carrier to realize this improvement, which requires more effort of the terminal operator.

It was assumed that switching from a seaside job to a landside job for the stacker/reclaimer does not take time. However, practical data showed that the belt conveyors, which are connected to the stacker/reclaimer, have to run empty for approximate fifteen minutes to prevent contamination between the different bulk materials. During these fifteen minutes the machine needs to be repositioned as well. When this aspect will be considered, the possible improvement for the FIFO+ operational procedure will be decreased slightly.

ACKNOWLEDGMENTS

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