ANALYZING THE EFFICIENCY OF DRY BULK CARGO HANDLING AT THE INLAND PORT TERMINAL USING SIMULATION AND DEA

Danijela Pjevčević*
University of Belgrade, Faculty of Transport and Traffic Engineering, danijela@sf.bg.ac.rs
Ivana Vladisavljević
University of Belgrade, Faculty of Transport and Traffic Engineering, ivana.vladisavljevic@gmail.com
Katarina Vukadinović
University of Belgrade, Faculty of Transport and Traffic Engineering, k.vukadinovic@sf.bg.ac.rs

Abstract: *With the purpose of planning cargo handling, analysis of terminal for dry bulk cargoes has been done and the proposals for capacity increase have been given in this paper. Three different scenarios of its treatment have been proposed and each scenario demands involvement of certain labor force, and main and auxiliary loading/unloading equipment. Simulation models of the proposed scenarios have been developed in this paper, with the purpose of analyzing measures of effectiveness of terminal for dry bulk cargoes, and examining their influence on terminal capacity. Besides the simulation results analysis, the analysis of efficiency of the proposed scenarios of cargo handling using Data Envelopment Analysis (DEA) method has been done. DEA method gives possibility of observing the efficiency of the proposed scenarios and their sub-scenarios of dry bulk cargo handling.*

Keywords: *dry bulk cargo handling, inland port terminal, data envelopment analysis.*

* Corresponding author

1. INTRODUCTION

One of the biggest challenges that port authorities are facing today is decreasing the vessel turnaround time. One of the ways to increase terminal productivity is to decrease the time vessels spend waiting to be served. The goal of the port management is to have a terminal that provides efficient and competitive service with high quality and low prices.

The goal of this study was to examine and plan, using simulation modeling and Data Envelopment Analysis (DEA) method, dry bulk cargo handling process at the Port "Danube", Pancevo [6]. The first objective was simulation modeling and analysis of dry bulk cargo handling, and calculation of measures of effectiveness (MOEs) for the terminal operation based on the simulation results. The second objective was application of DEA to calculate the efficiency of proposed scenarios and their sub-scenarios taking into consideration number of workers, utilized equipment and observed MOEs.

In this study, pushed barge convoys were used on inland waterways to transfer dry bulk cargo to the berth. Loading and unloading was done using quay cranes. Thoroughly planed organization of cargo transfer to the storage area would contribute to the decrease in total costs through shorter time that vessel spend on the berth, higher utilization of used equipment and the reduction in the total service time.

This paper suggested three different scenarios of planned cargo handling process, where each scenario requires employment of corresponding labor force as well as main and auxiliary reloading equipment. Simulation models of proposed scenarios were developed with the purpose of analyzing MOEs for the inland port terminal that is used for the handling of dry bulk cargo. Collected and analyzed MOEs were average vessel service time, average vessel waiting time, quay crane utilization, and packer utilization. Simulation models for eight sub-scenarios were developed for both first and second scenarios. More precisely, observed models included alternatives where one and two quay cranes were used for cargo handling, and the cargo was transferred to the storage area using two to five trucks. Cargo handling in the third scenario was done using one and two quay cranes. Transfer to the storage area was done by belt conveyer. Thus, this study modeled and analyzed the total of 18 sub-scenarios.In addition to the simulation results analysis, analysis of the efficiency of the proposed alternatives for the cargo handling was done using DEA methodology [3]. DEA method provides the opportunity to measure the efficiency of Decision Making Units (DMUs) for the proposed scenarios and their sub-scenarios, including number of workers, number of quay cranes and average vessel service time.

2. METHODOLOGY

2.1 Proposed Scenarios for the Dry Bulk Cargo Handling

Ideas for the proposed alternatives came from the collaboration with the employees in the Planning and Development Sector at the Port "Danube" Pancevo. The plan was to handle dry bulk cargo, more precisely, the fertilizer, at the port terminal. Fertilizer was transported to the port as a bulk cargo using pushed barge convoys (in further text, referred to as vessels). Cargo was further unloaded from the vessels using port quay cranes placed on the berth. Although fertilizer came to the port as a bulk cargo, its further transport required packing it in the bags. Port management had a goal to conceptualize the fertilizer handling in such way that would maximize the efficiency of the handling process without slowdowns, minimize vessel turnaround time, and maximize the utilization of equipment. To achieve that goal, the port management was considering two possibilities for fertilizer packing. First alternative was packing in bags directly on the berth, and second alternative was packing within the storage area. In addition, transfer of the fertilizer from the berth to the storage area was done either using trucks of belt conveyer. Further fertilizer handling consisted of stacking/arranging bags on palettes, which were further, according to the outside requests, either moved to the storage or directly distributed. Each of the considered alternatives required employment of the certain labor force and main and auxiliary reloading equipment necessary for quality fertilizer handling and for efficiently operated port terminal. Number of employed workers was determined based on the used technologies and depending on the reloading equipment. Based on these requirements, three scenarios for the fertilizer handling were proposed. Their detailed explanation follows.

First Scenario: Fertilizer came to the berth of a port terminal on the pushed barge convoy by inland waterways. The packer was located on the berth, and the fertilizer was directly transferred from the barge into the packer's bin using quay crane. Packer is used to pack fertilizer into plastic bags. Bags were, further, manually loaded in a truck and transported to the closed storage area. Within the storage area, the truck was unloaded and, then, it returned to the berth for next loading. Fertilizer bags were palletized in the storage area for the purpose of further distribution. Palletized fertilizer was loaded into trucks for inland distribution or stored in the storage area depending on the current demands. In order to collect data for the analysis, eight simulation models were developed. Keeping all other inputs fixed, number of quay cranes and number of trucks were varied. One or two quay cranes were reloading cargo from the barge to the packer's bin; and the number of trucks used to transfer cargo from the berth to the storage area was varied from two to five.

Second Scenario: Second scenario of fertilizer handling considered reloading fertilizer directly into dump truck using quay crane, and further transporting the fertilizer to the closed storage area, over the truck weight station. Within the storage area, the truck dumped the fertilizer. While returning to the berth for new loading, it stopped on the weight station. Further cargo handling was done within the storage area where the fertilizer was loaded into packer's bin using a loader. Bagged fertilizer was put on pallets. Forklift put pallets either onto the truck for inland distribution or stored them in the storage area, according to the current demands. Same as in the first scenario, eight simulation models were developed, varying number of quay cranes (one and two) and number of trucks (two, three, four, and five) keeping all other inputs fixed.

Third Scenario: Third scenario considered reloading the fertilizer, using a quay crane, directly on belt conveyer (the continuous reloading equipment). Using the belt conveyer, dry bulk cargo was transferred from the berth to the storage area; more precisely, it was transferred directly in the packer's bin. Same as in the previous two scenarios, fertilizer was packed in the plastic bags, palletized, and transferred using forklift, to either truck for inland distribution or stored into the storage area. For this scenario two simulation models were developed varying only number of quay cranes (one and two) while keeping all other inputs fixed.

2.2. Simulation Model Development

In order to compare proposed scenarios, simulation models for each scenario and sub-scenario were developed. The simulation is considered to be one of the most powerful methodologies for analyzing potential success of the proposed scenarios. The simulation provides the opportunity to experiment with infrastructure, technology and operations without any real investments. All models were tested on the corresponding numerical examples. In order to analyze performance indicators of the observed port terminal, simulation models of proposed alternatives for dry bulk cargo handling were developed in the simulation software package Flexsim (Flexible Simulation Software, Version 3.0, www.flexsim.com). Initial assumptions for the simulation experiments were set up based on the information obtained from the Planning and Development Sector at the Port "Danube" Pancevo:

- Pushed barge convoys' interarrival time was represented with normal distribution with μ=3 days and σ=1 day;
- Quay crane's unloading time was represented with normal distribution with μ=360 s and σ=60 s;
- Time to pack a fertilizer bag was represented with normal distribution with μ=3 s and σ=1 s;
- Speed of belt conveyer was v = 3 m/s;
- Average truck's speed was v = 15 km/h.

2.3. Measures of Effectiveness

In this study, following measures of effectiveness (MOEs) were defined and analyzed:

- Average vessel service time (time measured from the moment when unloading process starts till the moment when the last cargo quantity is transported to the storage area);
- Average vessel waiting time (average time that pushed barge convoy spends in the port till it is moved to the berth where it will be processed);
- Average quay crane utilization (the average time that quay crane spends unloading cargo divided by the observed time interval);
- Average packer utilization (the average time the packer spends packing fertilizer in bags divided by the observed time interval).

2.4. Description of the Proposed DEA Model

In this study, 16 alternatives for fertilizer handling, as DMUs, were evaluated. Eight sub-scenarios from the first and eight sub-scenarios from the second scenario were considered; whereas, the third scenario was not included in DEA analysis. The goal of port management was the employment of reloading equipment and labor force for the fertilizer handling in such way to minimize the vessel turnaround time and to improve the overall operational indicators.

Very important step in the DEA model development is proper selection of inputs and outputs. After correlation analysis and the analysis of how the change in inputs and outputs impacts the efficiency of observed scenarios, the DEA model with two inputs: number of workers and number of quay cranes, and one output: the reciprocal of average vessel service time, was chosen.

3. ANALYSIS OF THE SIMULATION RESULTS

This study observed terminal operations in duration of 90 days [8]. Terminal operates in two eight-hour shifts. Within the observed time interval, and based on the assumed arrival rate, 23 pushed barge convoys with the fertilizer arrived at the port, and needed to be serviced.

3.1. Simulation Results for the First Scenario

Table 1 provides MOEs collected in simulation experiments for the first scenario.

Table 1. MOEs for the first scenario

	Number of trucks	Average vessel service time (days)	Number of serviced vessels	Average vessel waiting time (days)	Average utilization of quay crane I	Average utilization of quay crane II	Average utilization of packer I	Average utilization of packer II
One quay crane	2	5.64	16	13.6	0,91		0.38	0.38
	3	5.33	17	10.6	1		0.42	0.42
	4	5.32	17	10.6	1		0.42	0.42
	5	5.31	17	10.6	1		0.42	0.42
Two quay cranes	2	5.61	16	12.6	0.53	0.41	0.39	0.39
	3	3.94	23	0.54	0.73	0.60	0.55	0.55
	4	3.93	***23***	***0***	***0.71***	***0.63***	***0.56***	***0.55***
	5	3.92	23	0	0.70	0.64	0.56	0.56

Table 1 shows that using two quay cranes and four trucks for the first scenario gave the best results among eight observed sub-scenarios. Waiting time of the vessel was reduced to zero, number of processed vessels was equal to the number of arrived vessels within the observed time period, and utilization of quay cranes and packers was satisfactory.

3.2. Simulation Results for the Second Scenario

Table 2 provides MOEs collected in simulation experiments for the second scenario.

Table 2 shows that using two quay cranes and five trucks for the second scenario gave the best results among eight observed sub-scenarios. Similarly to the first scenario results, waiting time of the vessel was reduced to zero, number of processed vessels was equal to the number of arrived vessels within the observed time period, and utilization of quay cranes and packers was satisfactory.

Table 2. MOEs for the second scenario

	Number of trucks	Average vessel service time (days)	Number of serviced vessels	Average vessel waiting time (days)	Average utilization of quay crane I	Average utilization of quay crane II	Average utilization of packer I	Average utilization of packer II
One quay crane	2	7.20	13	20.5	0.77		0.52	0.52
	3	5.62	17	9.9	0.96		0.61	0.61
	4	5.63	17	9.6	0.99		0.63	0.63
	5	5.34	17	8.6	0.99		0.64	0.64
Two quay cranes	2	6.40	14	17.9	0.52	0.32	0.53	0.53
	3	4.30	21	1.6	0.72	0.54	0.65	0.65
	4	4.10	22	0.2	0.67	0.69	0.66	0.66
	5	3.91	***23***	***0***	***0.69***	***0.69***	***0.67***	***0.66***

3.3. Simulation Results for the Third Scenario

Table 3 provides MOEs collected in simulation experiments for the third scenario.

Table 3. MOEs for the third scenario

	Average vessel service time (days)	Number of serviced vessels	Average vessel waiting time (days)	Average utilization of quay crane I	Average utilization of quay crane II	Average utilization of packer I	Average utilization of packer II
One quay crane	5.35	17	7.9	1.00		0.42	0.41
Two quay cranes	4.70	19	5.1	0.67	0.49	0.49	0.49

MOEs displayed in table 3 show that demands for the fertilizer handling without vessel waiting times in the third scenario cannot be achieved using either one or two quay cranes. Improvements in the observed MOEs could be possibly done by changing the reloading characteristics of observed equipment, which would decrease the average vessel service time and average vessel waiting time.

3.4. Summary of the Simulation Results

Table 4 summarizes the two sub-scenarios (one from the first and one from the second scenario) that serviced the vessels without waiting time. The third scenario did not give any alternative that serviced the vessels without waiting time, and, thus, it was not included in this summary and in the further analysis.

4. EFFICIENCY ANALYSIS USING DEA METHODOLOGY FOR DRY BULK CARGO HANDLING

Based on the simulation results analysis, it can be concluded that first and second scenarios (employing four trucks and two quay cranes, and five trucks and two quay cranes, respectively) could process the cargo without waiting times. Since the third scenario did not meet current demands for dry bulk cargo handling at the port terminal, it was excluded from the efficiency analysis using DEA methodology.

Table 4. Sub-scenarios that serviced the vessels without waiting time

Scenario	Number of cranes	Number of trucks	Average convoy handling time (days)	Number of handled convoys	Average waiting time (days)	Average utilization of crane I	Average utilization of crane II	Average utilization of packer I	Average utilization of packer II
1	2	4	3.93	23	0	0.71	0.63	0.56	0.55
2	2	5	3.91	23	0	0.69	0.69	0.67	0.66

The goal of DEA methodology application was to investigate the efficiency of proposed sub-scenarios for the first two scenarios, that is, to point to the combination of input and output values that provides the efficient fertilizer handling at the port terminal. Proper DEA model development depends on the selection of inputs and outputs and their correlation. In this study, the authors chose the model with two inputs: number of workers and number of quay cranes, and one output: the reciprocal of average vessel service time.

This study evaluated 16 scenarios for fertilizer handling process at the port terminal. Each scenario represents a separate DMU, as follows:

- DMU1: first scenario-1 quay crane and 2 trucks;
- DMU2: first scenario-:1 quay crane and 3 trucks;
- DMU3: first scenario-1 quay crane and 4 trucks;
- DMU4: first scenario-1 quay crane and 5 trucks;
- DMU5: first scenario-2 quay cranes and 2 trucks;
- DMU6: first scenario-2 quay cranes and 3 trucks;
- DMU7: first scenario-2 quay cranes and 4 trucks;
- DMU8: first scenario-2 quay cranes and 5 trucks;
- DMU9: second scenario-1 quay crane and 2 trucks;
- DMU10: second scenario-1 quay crane and 3 trucks;
- DMU11: second scenario-1 quay crane and 4 trucks;
- DMU12: second scenario-1 quay crane and 5 trucks;
- DMU13: second scenario-2 quay cranes and 2 trucks;
- DMU14: second scenario-2 quay cranes and 3 trucks;
- DMU15: second scenario-2 quay cranes and 4 trucks;
- DMU16: second scenario-2 quay cranes and 5 trucks;

Software Efficiency Measurement System [9] (Software Efficiency Measurement System, LP

Solver DLL n.d.) was used to solve suggested DEA model.

Table 5 shows inputs and outputs, as well as calculated efficiencies for the proposed DEA model.

Efficiency measurement and analysis of the proposed scenarios and their sub-scenarios using DEA method was done in order to choose the most suitable scenario for the fertilizer handling process in the Port “Danube” Pancevo.

Based on the calculated values, shown in Table 5, efficient sub-scenarios (in terms of the number of employed workers, the number of used cranes and the average vessel service time) were DMU2, DMU3, DMU4 and DMU6. With the efficiency that equals to one, these DMUs represent boundary of efficiency. DMUs with the efficiency less than one indicate that there is a need to decrease input values so they can become efficient for given output.

Table 5. The efficiencies of evaluated scenarios

	Inputs		Outputs	
Decision Making Unit	Number of workers	Number of quay cranes	Reciprocal of average vessel service time	Efficiency
DMU1	30	1	0.1773	98.76%
DMU2	32	1	0.1876	100.00%
DMU3	34	1	0.1880	100.00%
DMU4	36	1	0.1883	100.00%
DMU5	32	2	0.1783	74.62%
DMU6	34	2	0.2538	100.00%
DMU7	36	2	0.2545	97.16%
DMU8	38	2	0.2551	94.48%
DMU9	34	1	0.1389	73.89%
DMU10	36	1	0.1779	94.48%
DMU11	38	1	0.1776	94.32%
DMU12	40	1	0.1563	99.44%
DMU13	36	2	0.1563	59.66%
DMU14	38	2	0.2326	86.13%
DMU15	40	2	0.2439	87.71%
DMU16	42	2	0.2558	89.37%

For example, the least value for efficiency was 0.59 for the DMU13, which means that in order to achieve the efficiency with the current output value, it is necessary to decrease inputs by 41%.

Basic CCR DEA model gave multiple units with the efficiency equal to one. However, this model does not provide the way to determine which of those efficient units is the most efficient. For the purpose of ranking these efficient DMUs, the method of super-efficiency was used [1]. The results are shown in Table 6. This method provides the way to rank the efficient DMUs, and to choose the unit with the highest efficiency.

The super-efficiency method enabled ranking among efficient units (DMU2, DMU3, DMU4, and DMU6) and finding the unit with the highest efficiency (DMU6). Specifically, the highest efficiency was obtained for the first scenario of dry bulk cargo handling with the employment of two quay cranes and three trucks. Second efficient cargo handling procedure was also first scenario, but with the employment of one quay crane and three trucks; followed also by the first scenario with the employment of one quay crane and five trucks. The last ranked sub-scenario in terms of efficiency was the second scenario with the employment of two quay cranes and two trucks.

Table 6. The rank of evaluated scenarios

Scenario	Efficiency	Rank
DMU1	98.77%	6
DMU2	102.71%	2
DMU3	100.03%	4
DMU4	100.16%	3
DMU5	74.64%	14
DMU6	105.59%	1
DMU7	97.18%	7
DMU8	94.49%	8
DMU9	73.88%	15
DMU10	94.48%	9
DMU11	94.32%	10
DMU12	99.47%	5
DMU13	59.68%	16
DMU14	86.15%	13
DMU15	87.71%	12
DMU16	89.39%	11

5. CONCLUSIONS

This study developed simulation models and performed the efficiency analysis using DEA methodology of the proposed scenarios for the dry bulk cargo handling at the inland port terminal.

Various scenarios for the fertilizer handling were proposed; each scenario and its sub-scenarios required employing certain number of workers as well as reloading machinery. Since the new process was observed, it was necessary to determine all variables that had an effect on the reloading and handling of the cargo. The results of this research could help the port management to set up the initial equipment, and to aid in the further operational management.

Based on the proposed scenarios, simulation models were developed. First and second scenarios of fertilizer handling varied the number of cranes (one and two) and the number of trucks (two, three, four, and five). Third scenario, used conveyor belt instead of trucks, thus, only the effect of the number of cranes (one and two) on the collected MOEs was observed.

The analysis of simulation results pointed to the number of cranes and number of trucks which was necessary to use to process the pushed barge convoy without any waiting time, in other words, to determine the capacity of the port terminal for dry bulk cargo assuming that vessels do not wait for unloading. Handling convoy without waiting time in the first scenario was accomplished employing two cranes and four trucks; while, for the second scenario, it was necessary to employ two cranes and five trucks. This indicates that the first scenario met the requirements with one less truck, that is, with fewer investments. Results from the third scenario indicate that convoy waited for unloading with employment of either one or two cranes. For that reasons, the third scenario was excluded from the further analysis. Further analysis of the third scenario in terms of the change in the number and characteristics of all participants in the proposed handling process could possibly decrease waiting time, decrease time for the vessel serving and increase the capacity, and could be the topic for future research.

The contributions of this paper are development of simulation models for the dry bulk cargo handling process at the port terminal, definition and collection of MOEs for various conditions, and establishing satisfactory operational management on the terminal. The analysis of the simulation results pointed to the problem solving dynamics (removing port bottlenecks) with the purpose of improving MOEs for the cargo handling in current conditions. Developed simulation models have practical application in water transportation and can be expended for further research to analyze diverse cargo types that are moved simultaneously in both directions (import and export).

For determining the efficiency of the proposed scenarios using DEA methodology, the number of quay cranes and the number of workers were used as inputs; the reciprocal of average vessel service time was used as an output. The application of basic CCR DEA model gave four efficient units (DMU2, DMU3, DMU4, and DMU6). Further, modified DEA model ranked these efficient units, and singled out DMU6 (the first scenario of fertilizer handling with employment of two cranes and three trucks) as the most efficient sub-scenario.

Hence, DEA methodology pointed to the first scenario that employed two quay cranes and three trucks in terms of efficiency; whereas, simulation results pointed to the first scenario that employed two cranes and four trucks. MOEs, from the simulation experiments, for these two sub-scenarios were close in value, except for the average waiting time. If three trucks were used, the waiting time for the pushed barge convoy was 13 hours, but when number of trucks was increased to four, the waiting time was reduced to zero. However, applied DEA methodology, regardless of waiting time, singled out the sub-scenario that employed three trucks as the most efficient, because, compared to other sub-scenarios, it represents appropriate sub-scenario of dry bulk cargo handling process in terms of employed number of workers, used equipment and average vessel service time.

This paper used the original approach to analyze, model and optimize the efficiency of the dry bulk cargo handling process at the inland port terminal. Developed models can be broaden and practically applied to the process of handling other types of cargo. The analysis of inefficient DMUs and increase of their efficiency can be one of the future research topics.

ACKNOWLEDGMENT

This work was supported by the Ministry of Education, Science and Technical development of the Government of the Republic of Serbia through the project TR36002, for the period 2011-2014.

REFERENCES

[1] Anderson, P., Petersen N., 1993. *A procedure for ranking efficient units in data envelopment analysis,* Management Science 39 (10), 1261-1264.

[2] Bugaric, U., Petrovic D., 2007. *Increasing the capacity of terminal for dry bulk cargo unloading*, Simulation Modeling Practice and Theory 15, 1366-1381.

[3] Cooper, W., M.L. Seiford, Zhu J., 2004. *Handbook on data envelopment analysis,* Boston.

[4] Cullinane, K., Song D-W., Ji P., Wang T-F., 2004. *An application of DEA windows analysis to container port production efficiency*, Review of Network Economics 3, 184-206.

[5] Nam, K.C., Kwak K.S., Yu M.S., 2002. *Simulation study of container terminal performance*, Journal of Waterway, Port, Coastal and Ocean Engineering 128 (3), 126-132.

[6] Pjevcevic, D., Vukadinovic, K., Vladisavljevic, I., Teodorovic, D., 2011. *Application of DEA to the analysis of AGV fleet operations in a port container terminal,* Procedia - Social and Behavioral Sciences, 20, 816-825.

[7] Pjevcevic, D., Vukadinovic K., 2010. *Efficiency measurement of bulk cargo handling at river port using data envelopment analysis,* National Journal Tehnika - Transport 4, 14-18.

[8] Pjevcevic, D., 2007. *Contribution to the research of a port terminal capacity for dry bulk cargoes*, Master's thesis, University of Belgrade, Faculty of Transport and Traffic Engineering.

[9] *Software Efficiency Measurement System, LP Solver DLL.* http://www.netlib.org.