Modelling the performance of port terminals using microsimulation

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Abstract

Globalization has caused an increase in cargo volumes in ports, which is starting to produce congestion in some of the main ports, delays in the whole supply chain, higher costs, retention in the vicinity of ports, and more pollution. All of these issues highlight the need to improve current container terminals by searching for enhanced management models.

The terminal operating system (TOS) is the operational control system used in container terminals. An improvement of TOS with better functionalities, and their optimization, would increase the efficiency of the terminal. In a previous study, the authors identified and weighted TOS functionalities using the analytic hierarchy process (AHP) method. The aim of this paper is to analyse by simulation how the improvement of the most influential TOS functionalities affects the operational and the environmental performance of a container terminal. Two new TOSs (TOS 2 and TOS 3) were compared with the TOS (TOS 1) currently used at Intersagunto terminal (Spain) by microsimulation using FlexTerm.

Results show that modifications to the TOS can improve certain operational aspects, such as the number of containers handled, the occupation of the storage yard, and the dwell times; however, there were not significant improvements in energy consumption and carbon footprint. Further developments should address this issue by modifying other TOS functionalities in order to obtain both operational and environmental improvements at the terminal. This paper is addressed to managers of container terminals, TOS designers, researchers in the field of ports and terminals, and port authorities.

Keywords: terminal operating systems (TOS); container terminal; microsimulation

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1. Introduction

Cargo volumes in ports increase every year due to globalization; this is starting to cause congestion in some of the main ports (e.g., Rotterdam, Hamburg, Los Angeles, and Radès), delays in the whole supply chain, higher costs, retention in the vicinity of ports, and more pollution. These issues highlight the need to improve current container terminals by searching for enhanced management models. Import and export traffic of goods has increased since 2009. In the last year, 2018, exports in Europe increased by 4% from €1879 billion euros in 2017 to €1955.7 billion euros in 2018; while imports increased by 6.6%, from €1857 billion euros in 2017 to €1980.4 billion euros in 2018 (Eurostat, 2019).

Terminal operating systems (TOS) are information and communication systems (ICT) used to control and monitor the movement of containers at a container terminal (Buhl & Schwientek 2016; Min et al. 2017; Jamal et al. 2017; Heilig & Voß 2017). Renken & Zander (2018) highlighted that there is high pressure to optimize terminal performance and a desire for increased efficiency, transparency, availability of data, and TOS information. An adequate design of container terminals would allow more efficient, safer, and more environmentally friendly transport. However, the selection of the best option is not simple because this depends on multiple criteria. The improvement of a TOS with better functionalities, and their optimization, would increase the efficiency of the terminal (e.g., increasing the container throughput and reducing operation time). Different studies can be found regarding the analysis of terminal performance through simulation and through the analysis of KPIs.

1.1. Previous simulation studies of port terminals

De Luca et al. (2015) analysed the prediction reliability and advantages of the use of microscopic and macroscopic simulation in container terminals using a case study. Macroscopic simulations are useful for the prediction of global performance indicators, whereas microscopic simulations allow the obtainment of disaggregated data related to handling equipment and single container movements. Angeloudis and Bell (2011) provided a classification and overview of container terminal simulation models and Stahlbock and Voß (2008) gave a wide overview of different simulation approaches developed for the increase of port efficiency. For example, Chandrakumar et al. (2016) studied, using simulation, how the implementation of LEAN and Green concepts in port terminals can enhance terminal productivity. El-Nasser and El-Horbaty (2015) used discrete-event simulation modelling to optimize solutions for a storage space allocation problem. Gudeli et al. (2010) used simulation and optimization techniques to improve the cooperation between the different equipment.

1.2. KPIs to measure port terminal performance

The identification and measurement of KPIs (key performance indicators) is very important for a good assessment of port terminals and TOS performance. A KPI is something that can be counted and compared, it provides evidence of the degree to which an objective is being attained over a specific time (Intrafocus, 2014).For simulation analysis, appropriate KPIs are those which i) offer valuable and objective information about the performance of the facility, and ii) can be extracted after the analysis of the port terminal performance using simulation methods.

Ha et al.(2017) compared the performance of four major container ports in South Korea (i.e., Busan North Port, Gwangyang, Incheon, and Busan New Port) based on six types of indicators: core activities, supporting activities, financial strength, user satisfaction, terminal supply chain integration, and sustainable growth. Morales-Fusco et al. (2016) analysed 27 KPIs corresponding to six main categories: traffic, finance, operations, custom procedures, sustainability, and human resources. Min et al. (2017) identified KPIs for the comparison of integrated and non-integrated TOS systems. The Intermodel EU (2017) project defined 27 key KPIs to measure the performance of terminals; these KPIs were grouped into operational, financial, quality, environment, and safety, and classified into three categories based on the ease of their obtainment. They concluded that KPIs that can be obtained more easily through simulation pertain to operational or service quality, and environmental indicators are not usually considered in simulation, but could be obtained through additional calculations. On the other hand, obtainment of safety and financial KPIs is very difficult.

In Hervás-Peralta et al. (2019) the authors obtained functionalities with higher importance and influence in achieving more efficient TOS and, then, more efficient and more environmentally respectful port terminals, using the analytic hierarchy process (AHP) method. This method was also applied in container terminal design problems by Molero et al. (2017) and Santarremigia et al. (2018). The functionalities with higher influence on TOS performance were: time tracking of vessels, container terminal yard optimization, development of loading lists for terminal operators with information about the cargo to be loaded/unloaded, and including information about its location. Other important functionalities are: emergency reports, retrieve and dispatch requests for gate operations, allowing customization of the layout, and providing extended data information about vessel voyages (e.g., security requirements or maintenance information). For the full list of TOS functionalities, see Hervás-Peralta et al. (2019). Within this paper, we go further by simulating how changes in functionalities, identified as those with a higher influence on TOS efficiency, affect the performance of the terminal. After an analysis of the previous state-of-the-art, the authors decided to: i) use microsimulation for the evaluation of different TOSs in port terminal performance, and ii) measure KPIs pertaining to the operational, quality, and environment areas.

The main objective of this paper is to analyse port terminal performance, using different levels of TOS systems, by microsimulation. Intersagunto terminal (Sagunto, Spain) was used as a case study. Three different TOS systems were simulated: TOS 1 (TOS currently used at the terminal), TOS 2 and TOS 3 (two new TOS systems).

The rest of the paper is structured as follows: Section 2 gives a description of the methodology followed. Section 3 compares the performance of the three TOS systems, considering operational, quality, and environmental indicators. Finally, Section 4 presents the conclusions of the paper.

2. Methodology

The overall goal of the global investigation is the optimization of TOS. For this, in the previous study the authors identified a list of the most important functionalities of a TOS by using AHP, with the help of an expert panel that covered all the port and container terminals stakeholders. In this paper the authors use microsimulation to analyze the influence of the most important TOS functionalities in the container terminals and ports performance.

The methodology used to analyse the influence of TOS functionalities on the terminal performance was:

- **Step 1:** The model was built on the basis of the current TOS system used at Intersagunto terminal, using the FlexTerm microsimulation tool (Chen et al. 2013).
- **Step 2:** New TOS systems (TOS 2 and TOS 3) were designed based on improving

the functionalities identified as those with a higher influence on the terminal performance by Hervás-Peralta et al. (2019). Changes made in the new TOS systems were focused on new technological processes, aimed at improving the terminal efficiency.

- **Step 3:** The FlexTerm microsimulation tool was applied to monitor operational, quality, and environmental KPIs in a simulated environment for TOS 2 and TOS 3.

2.1. Building the simulation model (TOS 1)

FlexTerm was used for the simulation of container terminal performance using the different TOS systems. FlexTerm is a discrete simulation program that allows simulation of container terminal operations and the analysis of existing operations, terminal expansion, and design of new container terminals (Chen et al. 2013).

First, the simulation model was built using real data (i.e., terminal layout, existing equipment, and its parameters and technological processes) obtained from Intersagunto terminal (Spain). Data about the functioning of the terminal during 2017 was entered into FlexTerm to build the simulation model of the terminal; this model was used to simulate the functioning of two new TOS systems (TOS 2 and TOS 3) at the terminal. In the proposed simulation model, mobile objects represented quay and yard equipment. The fixed facilities represented cranes and the container yard, which were directly linked to mobile objects by backlinks. In the simulation model, FlexTerm entities were containers that are routed from fixed or mobile objects to other objects. Containers were moved from a crane to a mobile object, such as a yard tractor that transports containers to a container yard. All the connections, rules and data were implemented in accordance with real time processes at Intersagunto terminal. The developed model is shown in Fig. 1.

After model definition and the correlation of set objects, parameters and system behaviour, the testing of individual activities, objects, their conditions, and interrelationships was carried out to validate the model; simulation experiments with current TOS parameterization (TOS 1) were also developed. A total of 120 iterations in 1 year intervals were developed.

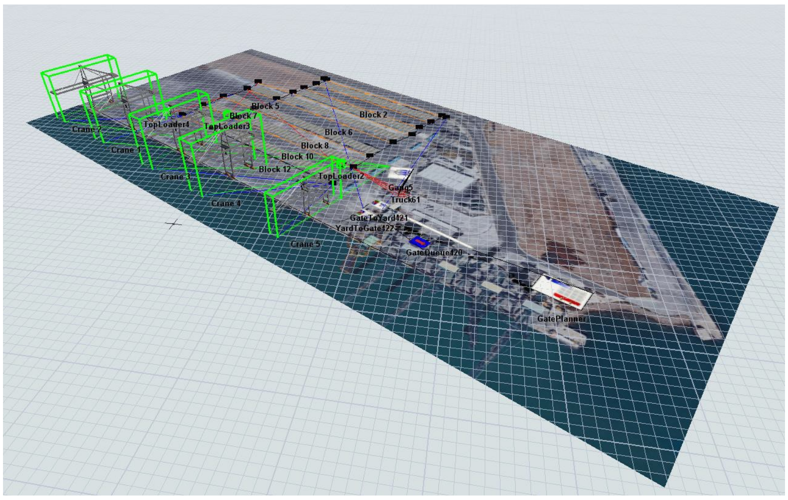

Fig. 1. Simulation model of Intersagunto terminal

2.2. Design of new TOS systems (TOS 2 and TOS 3) and simulation in FlexTerm

Table 1 shows selected TOS functionalities identified as the most influential in terminal performance in a previous study, and the related setup parameters for simulation purposes. In order to improve the performance of the terminal, two new TOSs (TOS 2 and TOS 3) were designed and these focused on the improvement of these functionalities.

Table 2 shows simulation parameters used for the simulation of each TOS (TOS 1, TOS 2, and TOS 3) and their relation with each of the selected functionalities.

Table 1. TOS functionalities analysed and related setup simulation parameters.

Functionality			Simulation setup parameters
A. Yard management	*Yard configuration*	A1. Customizable layout A2. Space optimized A3. Location optimized	Nº tiers of empty containers
	Technical optimizations	A4. Operating procedures	Administrative procedures (truck pick-up/drop-off) Equipment assignment (blocks)
B. Berth management and scheduling	*Berth management*	B1. Time tracking	Containers storage average time Min. setup time Administrative time (Truck pick-up/drop-off)
C. Port and vessel operations	*List & confirmations*	C1. Loading lists C2. Updated lists	Min. setup time
D. Gate in and gate out management	*Gate in and gate out management*	D1. Manage/control capacity limits	Containers storage average time Nº tiers of empty containers
E. Inventory & Warehouse Management	*Inventory Management*	E1. Track & manage inventory	Administrative time reduction (truck pick-up/drop-off) Equipment usage/assignment
F. Track & Trace	*Track & Trace*	F1. Vehicle traceability F2. Track/locate cargo	Equipment usage/assignment

Table 2. Simulation variables for each TOS and corresponding TOS functionality (defined in Table 1).

Simulation variables	TOS 1	TOS 2	TOS 3	Functionality
Container storage average time	Full - 5 days Empty - 21 days	Full - 4 days Empty - 15 days	Full - 4 days Empty - 10 days	B1, D1
Minimal setup time (container list)	-	60 min decreased	60 min decreased	B1, C1, C2
Number of tiers of empty containers	4	4	6	A1, A2, A3, D1
Truck yard drop-off time	8 minutes	8 minutes	7 minutes	A4, B1. E1
Truck yard pick-up time	13 minutes	13 minutes	12 minutes	A4, B1. E1
Number of yard tractors	4	4	5	F1
Use of reach stacker	Dedicated	Dedicated	For all blocks	A4, E1, F1, F2

2.3. Application of the FlexTerm microsimulation tool to TOS 2 and TOS 3

A total of 120 simulation iterations of 1 year intervals were developed and used for the comparison of the three TOS systems. Energy consumption and carbon emissions were calculated for each TOS from the operational data obtained from the simulations.

Electric energy (E_{CHE_i}) and fuel consumption (F_{CHE_i}) were calculated for each container handling equipment (CHE) (i.e., cranes, reach stackers, and yard tractors) using equations 1 and 2 respectively:

$$E_{CHE_i} = t_i \cdot E_c \quad (1)$$

$$F_{CHE_i} = \bar{d}_{CHE_i} \cdot f_{CHE_i} \quad (2)$$

where E_c is the energy consumption per container move, which for cranes is 6kWh (Van Duin & Geerlings 2011), t_i is the number of working hours, which is calculated as the ratio between the net moves per year and the average number of movements per hour of one CHE, which for cranes is 13.61 movements/h; $\bar{d}_{CHE_i}$ is the average distance travelled in a year by the CHE, and f_{CHE_i} is the CHE variable consumption, which is 5 L/km for reach stackers and 4 L/km for yard tractors (Van Duin & Geerlings 2011).

Equation 3 was used for the calculation of the carbon footprint of the terminal for each TOS simulation (CF_{TOS_i}).

$$CF_{TOS_i} = \sum_{i=1}^{n} E_{CHE_i} \cdot f_{elec} + \sum_{i=1}^{n} F_{CHE_i} \cdot f_{diesel} \quad (3)$$

where f_{elec} is the CO_2 emission factor in the Spanish electricity grid = 0.363 kg/kWh (Merlak et al. 2017) and f_{diesel} is the CO_2 emission factor for diesel = 2.65 kg CO_2/L (Van Duin & Geerlings 2011).

3. Results and discussion

3.1. Simulation results

Operational and quality key performance indicators were obtained from the simulation of the three TOS systems at the Intersagunto terminal. The outcomes were systematically divided into process parts focusing on: terminal throughput, container dwell time, and resource usage. Table 3 presents the container throughput and occupancy of the Intersagunto terminal as a result of simulation outcomes for TOS 1, TOS 2, and TOS 3. Results show an increase of 2142 TEU (4.3%) for TOS 2 and 2083 TEU (4.2 %) for TOS 3 compared with the initial situation (TOS 1). The simulation showed a decrease of the terminal yard occupancy due to the reduction of average container time storing, resulting in 17.44% occupancy after implementation of TOS 2 and 13.08% occupancy after implementation of TOS 3.

The implementation of new strategies for container storage in TOS 2 and TOS 3 resulted in reduced container dwell time (see

Table 4). Overall container dwell time was reduced with TOS 2 for 2.3 days, while TOS 3 reduced overall container dwell time by 3.47 days. Dwell time for full containers was reduced by 0.73 days for TOS 2 and by 0.79 days for TOS 3. In addition, dwell time of empty containers was significantly reduced, by 4.54 days for TOS 2 and 8.69 days for TOS 3.

Table 3. Terminal throughput and occupancy data for the three TOS systems

	Throughput (TEU)	Container yard occupancy (TEU)	Occupancy (%)
TOS 1	49401	1217	22.54%
TOS 2	51543	942	17.44%
TOS 3	51484	796	13.08%

Table 4. Container dwell time of TOS systems at Intersagunto terminal

	Dwell time (days)	Dwell time full	Dwell time empty
TOS 1	9.16	3.63	18.04
TOS 2	6.83	2.90	13.50
TOS 3	5.69	2.84	9.35

Reducing vessel setup time as a parameter in the TOS 2 and TOS 3 systems directly influenced the berth operational time, total vessel time spent on berth and vessel, and dock performance (see

Table 5). The current state simulation model set the parameter for average berth operational time at 743.78 minutes, while the implementation of TOS 2 and TOS 3 strategies decreased the average operational time to 741.00 minutes. Overall, the average operational time was reduced by 2.78 minutes. The total vessel time with the current TOS system is 932.10 minutes, while TOS 2 and TOS 3 significantly reduced it to 918.83 minutes, optimizing total vessel time spent on the berth by 13.27 minutes. Vessel performance with the current TOS is 25.8 TEU/hour, while implementing TOS 2 and TOS 3 strategies resulted in vessel performance of 26.7 TEU/hour. Dock performance with the current TOS is 19.2 TEU/hour, while implementing TOS 2 and TOS 3 strategies increased it to 20.7 TEU/hour.

Table 5. Berth and vessel operational time performance outcomes at Intersagunto terminal

	Operational time (min)	Total time (min)	Ship performance (TEU/h)	Dock performance (TEU/h)
TOS 2 and 3	741.00	918.83	26.70	20.73
TOS 1	743.78	932.10	25.80	19.20

3.2. Environmental KPIs

Table 6 and

Table 7 summarize, respectively, the fuel and electricity consumption obtained after the simulation of the functioning of the three TOS systems at Intersagunto terminal. Results show that the simulation of both TOS 2 and TOS 3 produced a small reduction in the average energy consumption (see

Table 7). This indicates that the improved efficiency of the cranes (which is the only CHE considered in terms of electrical consumption) is only possible to some extent. A maximum reduction of 2.47% was obtained for TOS 2. Regarding fuel consumption, the average fuel consumed per TEU using TOS 2 and TOS 3 shows a slight decrease from 2.16 L/TEU to 2.15 and 2.14 L/TEU, respectively.

Table 6. Fuel consumption at Intersagunto terminal using TOS 1, TOS 2, and TOS 3. RS: Reach stacker, YT: Yard Tractor.

	Total fuel consumed by RS (L)	*Average fuel consumed by RS (L/TEU)*	*Total fuel consumed by YT (L)*	*Average fuel consumed by YT (L/TEU)*	*Total fuel consumed (L)*	*Average fuel consumed (L/TEU)*
TOS 1	*9125.0*	*0.25*	27156	*1.90*	36281.0	2.16
TOS 2	*9490.0*	*0.24*	27594	*1.91*	37084.0	2.15
TOS 3	*8577.5*	*0.22*	27302	*1.92*	35879.5	2.14

Table 7. Electricity consumption at Intersagunto terminal using TOS 1, TOS 2, and TOS 3

	Energy consumed by cranes (kW)	**Energy consumed (%)[(1)]**	*Average electricity consumed by cranes per TEU (kW/TEU)*	*Average electricity consumed by cranes per TEU (%)[(1)]*
TOS 1	*277679.08*	-	19.46	-
TOS 2	*274589.47*	-1.11	18.98	-2.47
TOS 3	*274203.27*	*-1.25*	*19.27*	*-0.98*

(1) Compared with TOS 1.

Carbon emissions for each piece of container handling equipment working on the terminal, and the estimated global carbon footprint of the terminal for each TOS (CF_{TOS_i}) and average global carbon footprint per TEU (CFT_{TOS_i}), can be seen in

Table 8 and

Table 9. Results show that the simulations of TOS 2 and TOS 3 produced only a slight decrease in CO_2 emissions per TEU. As for energy consumption, the increase in the efficiency and the decrease of equipment routes through better control of the operations and an increase in yard storage capacity due to an additional stacking level show, from the simulations, that the CO_2 emissions per TEU for the simulated TOS characteristics can only be reduced by 1.4%.

Table 8. Carbon emissions of the container handling equipment used at Intersagunto terminal using TOS 1, TOS 2, and TOS 3.

	C_{crane} *(kg CO_2/year)*	*Crane kgCO_2/TEU*	$C_{Reach\ Stacker}$ *(kg CO_2/year)*	*Reach Stacker kgCO_2/TEU*	$C_{Yard\ Tractor}$ *(kg CO_2/year)*	*Yard Tractor kgCO_2/TEU*
TOS 1	*100797.51*	7.06	24181.25	0.67	71963.4	5.04
TOS 2	*99675.98*	6.89	25148.50	0.64	73124.1	5.05
TOS 3	*99535.79*	7.00	22730.37	0.58	72350.3	5.08

Table 9. Carbon emissions at Intersagunto terminal using TOS 1, TOS 2, and TOS 3

	CF_{TOS_i} *(kgCO_2/year)*	$\%CF_{TOS_i}$ (1)	CFT_{TOS_i} *(kgCO_2/TEU)*	$\%CFT_{TOS_i}$ (1)
TOS 1	196942.16	-	12.77	-

TOS 2	197948.58	+0.5	12.59	-1.4%
TOS 3	194616.46	-1.18	12.66	-0.9%

(2) Compared with TOS 1.

4. Conclusions

Increased container throughput in terminals is producing port congestion and a greater impact on the environment. Thus, a need for increasing port terminal performance has arisen. A higher terminal performance can be produced through the optimization of the TOS, increasing its efficiency through the inclusion and optimization of those TOS functionalities with better consequences for terminal performance. Within this paper, two new TOS systems, which were designed based on improvements to the most important functionalities identified in a previous study, were simulated by using FlexTerm and compared with the current TOS system used at Intersagunto terminal. Some of the functionalities modified in the TOS were: i) time tracking of vessels, ii) management and control of terminal capacity, iii) loading list, iv) yard optimization, and v) inventory tracking and management.

Simulations of TOS 2 and TOS 3 at Intersagunto terminal by applying the FlexTerm microsimulation tool show that modifications to the TOS can improve certain operational aspects, such as the number of containers handled, the occupation of the storage yard, and the dwell times; however, there were no significant improvements in energy consumption and carbon footprint. Further studies should address this issue by two approaches, i) modifying other TOS functionalities in order to obtain higher operational and environmental improvements at the terminal and ii) prove the same microsimulation process of this paper in others container terminals in order to assess if the results of this paper can be generalized

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