Exploring strategies in integrated container terminal planning tasks
A data-intensive simulation game analysis

Kurapati, Shalini; Lukosch, Heide K.; Cunningham, Scott; Kwakkel, Jan; Verbraeck, Alexander

Publication date
2016

Document Version
Final published version

Published in
Proceedings of ILS 2016 - 6th International Conference on Information Systems, Logistics and Supply Chain

Citation (APA)
Kurapati, S., Lukosch, H. K., Cunningham, S., Kwakkel, J., & Verbraeck, A. (2016). Exploring strategies in integrated container terminal planning tasks: A data-intensive simulation game analysis. In *Proceedings of ILS 2016 - 6th International Conference on Information Systems, Logistics and Supply Chain* International Conference on Information Systems, Logistics and Supply Chain.

Exploring Strategies in Integrated Container Terminal Planning Tasks: A Data-intensive Simulation Game Analysis

Shalini Kurapati[1], Heide K. Lukosch[1], Scott Cunningham[1], Jan Kwakkel [1], Alexander Verbraeck[1]

[1] Delft University of Technology, Faculty of Technology, Policy and Management, Jaffalaan 5, 2600 GA Delft, The Netherlands
{s.kurapati, h.k.lukosch, s.cunningham, j.kwakkel, a.verbraeck}@tudelft.nl

Abstract. Planning tasks in modern, fully automated container terminals require a high awareness of the complex situation, and successful planning strategies. Operational planning includes both strategies of planning and resource management. As planning procedures are not (yet) fully automated, a skilled workforce of planners is needed to conduct the complex operational planning of container terminal procedures and equipment. By using a simulation game, we explored which planning strategies are successful, leading to efficient and effective use of container terminal equipment. Our results show that through the game, we were able to identify three main strategies, of which one is associated with efficient unloading of vessels, and with high scores in game play. A second type of strategy, moderately rewarded, is associated with good handling of containers. The third type of strategies generally reflects players overwhelmed by increases in activity in the port, resulting in long wait times and a poor score at the game.

Keywords: Container Terminal Operations, Integrated Planning, Simulation Gaming, Strategies, Data Analytics.

1 Introduction: Complexity of Planning Tasks in Fully Automated Container Terminals

Container terminals are crucial nodes within the global supply network of goods. They can be characterized as complex socio-technical systems as they comprise of complex physical-technical systems and networks of interdependent actors (Saanen, 2004: de Bruijn & Herder, 2009). Operational planning is the backbone of container terminal operations (Meisel, 2009). Operations planning consists of two main components— planning (often iterative) and resource management. It is all about planning and utilizing the available resources efficiently, while optimally responding to dynamic situations to offer the highest service value to the customer (SteadieSeifi et al., 2014). The last decade witnessed an increase in automatic handling systems in

container terminals to make the operations of container terminals efficient, safe and cost-effective. However, operational planning in container terminals deals with a lot of dynamicity and stochasticity that makes automated solutions for operational planning problems extremely complex (SteadieSeifi et al., 2014).
Given the dynamic and stochastic nature of operational planning, automation, often, if not always, is still inferior to human intervention in the operational planning of container terminals (Angeloudis & Bell, 2010). The advent of modern and automated cargo handling systems, therefore created a dire need for a skilled workforce with renewed strategies to run the terminal (Turnbull & Weston, 1993). Automated handling systems and related rapidly progressing port technologies put a lot of pressure on terminal workforce as the factors and strategies affecting effective and safe performance haven't been well explored in operational planning, especially for integrated planning tasks (Nam & Ha, 2001; Notteboom, 2012). It is very important to identify competencies and strategies to train terminal operators for integrated planning tasks in container terminals. In our study, we explore the various planning strategies that predict performance at integrated planning tasks by using the method of simulation gaming, which is further explained in the following section.

2 Simulation Gaming for Integrated Planning

Simulation games are defined as 'a conscious endeavor to reproduce the central characteristics of a system in order to understand, experiment with and/or predict the behaviour of that system' (Duke, 1980). It is a method in which human participants enact a specific role in a simulated environment (Duke & Geurts, 2004). There is a wide variety of fields in which simulation games have been employed, both in research and practice, and for a broad range of purposes, like training, teaching, performing scientific research and experiments (Peters & Van de Westelaken, 2011; Van Os, 2012). Simulation games are a relatively novel research method in the field of supply chain, logistics and transportation (Meijer, 2009). In the context of the field, a simulation game is a model of the supply, logistics or transportation network, whereas human actors are not modeled but are integrated into the simulation by giving them a role. Their behavior can be studied in simulation gaming sessions (Meijer, 2009). Such sessions produce rich data, both quantitative and qualitative. The 'human-in-the-loop' characteristic of simulation gaming makes it an apt research instrument to fulfill the research objective of exploring player strategies for integrated planning tasks. Towards this objective, we developed a simulation game known as Yard Crane Scheduler (YCS) that represents the complexity of integrated planning tasks in container terminals. The game was developed on the basis of the principles of triadic game design (Harteveld, 2011), in association with practitioners of container terminal operations, and professional game developers. YCS game was developed in the Unity 3D game engine platform.

The YCS game (Figures 1 & 2) represents the top view of a container terminal with quay cranes, yard cranes, Automated Guided Vehicles (AGVs), hinterland trucks and deep sea vessels including their arrival and departure times. The processes around

AGVs, and hinterland trucks are automated. The key objective of the YCS game is to align the planning activities in the container terminal and to efficiently manage the resources—yard and quay cranes. The key activities in the YCS game are threefold:

1. Making an unloading plan for the containers of the incoming ships.
2. Allocating resources in the yard and the quay to fulfill the plan made in step one.
3. A bonus activity that involves serving the hinterland trucks as quick as possible to avoid congestion in the gate area.

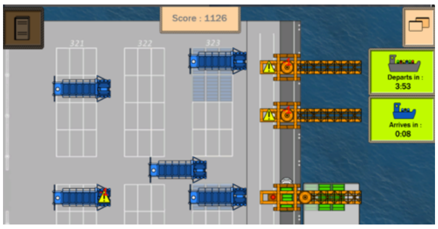

Figure 1. The start screen of YCS game

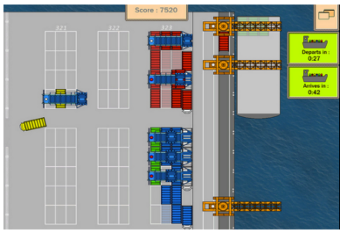

Figure 2. Operational mode of YCS game

Herewith, the YCS game represents a simplified, but still interrelated model of an automated container terminal. For a detailed account on the game design, mechanics, rule and scoring schema refer to Kurapati et al., 2014. The YCS game play generates both quantitative and qualitative data about game play behavior, choices and strategies. The qualitative data is recorded in the form of observations of player behavior, debriefing sessions and audio and videotaping. The quantitative data is logged in the form of various performance metrics of the YCS game as listed in Table 1. The following section delves into an exploratory data analysis using these performance metrics to understand player strategies in the game.

3 The Explorative Study with the YCS Game Data

3.1 Simulation Gaming Session Set-up

A total of 188 master level students of universities in The Netherlands, Germany and the United States participated in this research study with the approval of the ethics board of the concerned universities. These students were chosen because their study specialization was in the field of logistics, supply chain and transportation, the knowledge of which is a prerequisite to participate in our simulation gaming session. Students assembled in a lecture room equipped with laptops loaded with the online YCS game. They were given a brief introduction about the operational planning of container terminal operations. They were then introduced to the YCS game. Three online tutorials were provided to make the students familiar with the rules and mechanics of the YCS game. Two planning exercises with varying levels of difficulty (mission 1 and mission 2) were provided to the participants after the tutorial session. The demographics and other personal information were collected using a pre- and a post-game survey. The post-test-survey was administered to collect the opinions of the students regarding the game play and its teaching effect. The game data was logged in an online database. The following sub section explains the results obtained with the data gathered, and the methods of data analysis used for the study. Given the exploratory nature of the study, we used a partial data set comprising 78 students. Given the multiple game plays of the students, the total data points analyzed are 888.

3.2 Data Analysis: Results

The first step in analyzing the data is to use a dimensionality reduction technique. The benefits of such an analysis is to reduce a multi-dimensional dataset into a smaller set of features, which may be more easily visualized and understood. The variables collected and assigned in the game have very different units, so before analysis the data is unit normalized. Each variable in unit normalized data has a mean of zero and a standard deviation of one. The data is then analyzed using the Principal Components Analysis (PCA) technique. Unit norm data, when analyzed using PCA, results in a correlation analysis. The alternative, covariance analysis, is not selected since the units of measurement vary widely, and the resultant reduced dimensions would be dominated by the scaling of the variables.

Four reduced variables explain over 80% of the variance in the data (Table 2).

Table 1. Performance metrics in the YCS game

No.	Performance Metric	Description	Mean	Std. Dev.
1	BerthCranesUsed	The number of berth cranes used during the game	2.8	0.4
2	BonusEarlyVessel	Bonus points earned due to early departure of vessels	9744.3	9025.9
3	BonusSeconds	The difference between the duration (in seconds) of actual departure and early departure of vessels that lead to bonus points.	97.4	90.3
4	BonusYellowCainer	Bonus points for handling yellow containers carried away by hinterland trucks.	168.5	166.1
5	PlandAftArrival	Number of containers planned before arrival of the vessel	1.8	4.0
6	PlandBfArrival	Number of containers planned after the arrival of the vessel	13.9	11.7
7	LongstContainerIdle	The longest idle time of a container (seconds).	86.1	54.1
8	LongstInactiveBerth	The longest idle time of a berth crane (seconds)	46.6	48.2
9	LongstInactiveYard	The longest idle time of a yard crane (seconds)	107.8	101.7
10	LargeVesselsArrived	Number of large vessels that arrive in the game.	1.6	1.1
11	LeastEfficientBerthCrane	The idle time of the least efficient berth crane (seconds)	48.9	46.3
12	LeastEfficientYardCrane	The idle time of the least efficient yard crane (seconds)	106.2	96.5
13	MostEfficientBerthCrane	The idle time of the most efficient berth crane (seconds)	1.9	8.3
14	MostEfficientVessel	The waiting time for the most efficient vessel (seconds)	87.7	95.7
15	MostEfficientYardCrane	The idle time of the most efficient yard crane (seconds)	0.7	0.5

16	NotPlanned	The number of unplanned containers	2.6	3.8
17	PointsTotal Succes	Bonus points for successful handling of containers	1766.0	1561.0
18	Score	The overall game score	6310.8	7203.6
19	ScoreContainers	The points awarded for handling containers	1107.9	1373.3
20	ScoreVessels	The points awarded for handling vessel	9912.9	8942.8
21	SecsBerthCraneInactive	The idle time of all the berth cranes (seconds)	88.2	90.8
22	SecsContainerIdle	The waiting time for all the containers to be handled (seconds)	963.5	699.3
23	SecsWaitBerth	Waiting time for containers in the quay to be loaded onto the vessel (seconds)	94.0	87.1
24	SecsWaitInSchip	Waiting time for containers in the vessel (seconds)	486.6	394.3
25	SecsWaitInStack	Waiting time for containers in the yard (seconds)	245.3	221.1
26	SecsWaitYard	Waiting time for containers to be handled by yard cranes (seconds)	136.9	175.0
27	SecsYardCraneInactive	The idle time of all the berth cranes (seconds)	390.2	366.7
28	SmallVesselsArrived	Number of small vessels arrived	2.1	1.5
29	StarsContainers	Stars awarded for handling containers	1.4	1.1
30	StarsCranes	Stars awarded for handling cranes	3.3	1.7
31	StarsTotalScore	Total number of stars awarded based on total score	3.9	1.4
32	StarsVessels	Stars awarded for handling the vessels	3.1	1.6
33	StrafContainerIdle	Penalty points due to container idle time	-89.2	159.7
34	StrafCranesIdle	Penalty points due to crane idle time	-472.8	434.1
35	StrafTotaalUnsuccessful	Penalty points due to unsuccessful container handling	-568.9	553.1
36	TotalContainers	Total number of containers moved	17.1	12.4
37	TotalSuccesful	Total number of containers successfully handled	11.4	9.3
38	TotalUnsuccessful	Total number of containers that were not handled	5.7	5.5
39	TotalVesselsArrived	Total number of vessels arrived	3.7	2.4
40	TotalVesselsEarly	Total number of vessels that left earlier than scheduled	1.8	1.4
41	YardCranesUsed	Number of yard cranes used	5.0	1.2
42	YellowContainersCollected	The number of yellow containers picked up	1.7	1.7
43	YellowContainersLeft	The number of yellow containers left behind	0.3	0.7

Table 2. Component Variance and Cumulative Variance

	Component 1: Total activity	Component 2: Container and Berth Handling	Component 3: Total Score	Component 4: Containers and Vessel Trade-offs
Variance	52%	13%	11%	5%
Cum. Variance	52%	65%	76%	81%

The first component is associated with the general activity of the port. The total number of vessels (both small and large), the vessels planned for arrival, and the total number of containers in the port all load on this component. The component is associated with the use of many cranes, many of which are idle. The component is also associated with game penalties for inefficient use of the cranes. This variable may be more associated with variations across different missions within the game then it is with the planning or performance of the individual player. Table 3 shows a truncated list of loadings, showing the ten highest magnitude variables associated with this component.

The second component is associated with good container handling, active use of berths, and effective planning. However it is also associated with a high number of additional earned penalties, and generally longer waits in stack and in berths. The component may be associated with a large amount of parallel activities ongoing on the part of the player. The variable is more associated with player activities and choices than the game environment.

The third component is related to the total score of the game. This is associated with scores for containers and vessels, bonuses for early vessels and additional time awarded, and awards for the most efficiently unloaded vessel. Interestingly this component, which is associated with in-game incentives, is independent and

Component 1 : Total activity			**Component 2: Container and Berth Handling**	
Variable Name	Loading		Variable	Loading
TotalVesselsArrived	0.203		NotPlanned	-0.347
TotalContainers	0.200		LongstInactiveBerth	-0.291
SecsWaittInShip	0.193		StarsContainers	0.277
SecsYardCraneInactive	0.193		ScoreContainers	0.274
SmallVesselsArrived	0.192		SecsBerthCraneInactive	-0.259

orthogonal from the other measured elements of situation and player performance.

Table 3. List of loadings of Component 3 &4

LeastEfficientYardCrane	0.191		LeastEfficientBerthCrane	-0.224
Gametime	0.190		SecsWaitInStack	0.219
StrafCranesIdle	-0.189		TotalUnsuccessful	-0.205
YardCranesUsed	0.186		StrafTotalUnsuccessful	0.205
PlandBfArrival	0.186		SecsWaitBerth	0.172

Table 4. List of loadings of Component 3 &4

Component 3: Total Score			**Component 4: Containers and Vessel Trade-offs**	
Variable	Loading		Variable	Loading
Score	0.351		LongstContainerIdle	0.493
StarsTotalScore	0.294		SecsWaitInStack	0.388
StarsVessels	0.278		StrafContainerIdle	-0.259
ScoreVessels	0.271		StarsVessels	0.228
BonusEarlyVessel	0.266		TotalSuccess	-0.212
BonusSeconds	0.266		SecsWaitYard	0.195
MostEfficientVessel	0.222		BerthCranesUsed	-0.194
TotalVesselsEarly	0.214		SecsContainerIdle	0.193
BerthCranesUsed	0.172		MostEfficientVessel	0.174
ScoreContainers	0.160		StarsTotalScore	0.167

The fourth component reflects a performance trade-off between the handling of the containers and the handling of the vessels. The performance variable is associated with high idleness on container, high penalties for containers, and long waits in stacks. On the other hand the component is associated with efficient loading of vessels, and stars awarded for vessels. The obverse strategy, manifested by many players, entails efficient handling of containers, but a corresponding neglect in the management of the vessels. The variable is more associated with player activities and choices than the game environment.

Figure 3 presents a scatter plot of the performance of players across the 888 runs. Each run is represented by a point on the plot. The relative emphasis on the two strategy factors is represented by the position of the run on the x-y axes. The size of the point represents the over-all performance score given to the player. The plot shows three distinct families of strategies. The left-most strategies are associated with efficient unloading of vessels, and are awarded with high scores in game play. The right-most strategies, which are moderately rewarded, are associated with good handling of containers. The upper strategies generally reflect players overwhelmed by increases in activity in the port, resulting in long wait times and a poor score at the game, while the right most strategies indicate a medium performance.

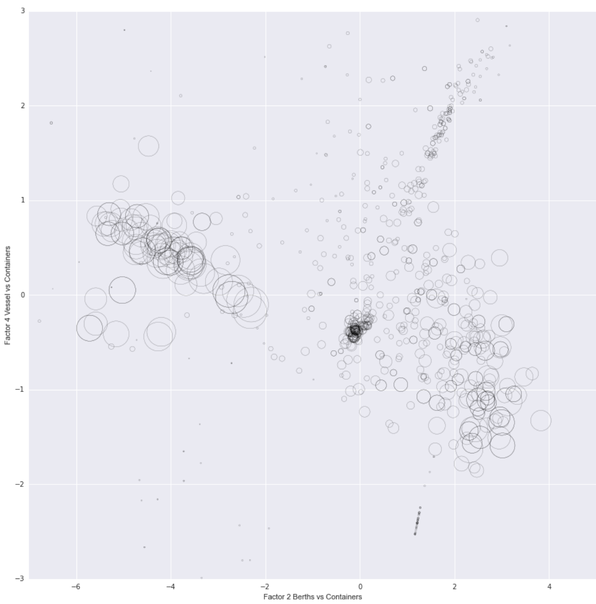

Figure 3. Scatter Plot of Player Strategies with Resultant Score

4 Conclusion & Future work

From the quantitative data collection of the game play, we were able to identify three main strategies of planning resources in a container terminal.

1. High performance strategy: Low vessel-turn-around time (the faster the vessels leave than expected schedule the lower the turn around time) seems to predict high scores in the game. Players who managed to efficiently handle the vessels performed the best. To enable the early departure of vessels, the players should efficiently plan and dynamically reposition the cranes and strategically plan the containers in the yard, which is a characteristic of integrated planning.
2. Medium performance score: The medium performing students focused on handling containers while neglecting the turn around times of the vessels.
3. Low performance strategy: The slow scoring players focused on all the components leading to cognitive overload and low score. It appears that a large part of the players were overwhelmed with the activity in the game

Our results imply that integrated planning tasks in fully automated container terminals require planners who are able to deal with a cognitive load of interrelated information from various sources and to handle different equipment simultaneously. The recommendations that follow these results include designing planning interfaces that assist the planner to reduce cognitive work load, as well as training planners to handle the cognitive load related to integrated planning operations.

Our future studies will follow two different pathways. The first one is to further analyze the game data to investigate even more details about the strategies players use and about the learning curve during game play. These findings could further throw light on the skills and knowledge needed for integrated planning tasks, which can help design the apt training programs for planners in container terminals. The second route of future research lies in the transfer of what we have learned from the game play to the real system. With professionals from the transportation and logistics field, we will further analyze the outcomes of our study to validate our results, and to formulate recommendations for real integrated planning strategies. The data-intensive analysis of a simulation game could hereby produce relevant insights for the improvement of a highly complex logistics system.

Acknowledgments. Dinalog, the Dutch Institute for Advanced Logistics, has funded this study.

References

Angeloudis, P., & Bell, M. G. (2010). An uncertainty-aware AGV assignment algorithm for automated container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *46*(3), 354-366.

De Bruijn, Hans, and Paulien M. Herder. "System and actor perspectives on sociotechnical systems." *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on* 39, no. 5 (2009): 981-992.

Duke, R. D. (1980). A Paradigm for Game Design. *Simulation and games*, *11*(3), 364-77.

Duke, R. D., & Geurts, J. (2004). *Policy games for strategic management*. Amsterdam:Dutch University Press.

Harteveld, C. (2011). *Triadic game design: Balancing reality, meaning and play*. London:Springer Science & Business Media.

Kurapati, S., Groen, D., Lukosch, H., & Verbraeck, A. Microgames in Practice: A Case Study in Container Terminal Operations. *The Shift from Teaching to Learning: Individual, Collective and Organizational Learning Through Gaming Simulation*, 333.

Meijer, S. (2009). *The Organisation of Transactions: Studying Supply Networks using Gaming Simulation.* PhD thesis. Wageningen University, The Netherlands.

Meisel, F. (2009). *Seaside operations planning in container terminals*. Berlin, Heidelberg: Physica-Verlag.

Nam, K. C., & Ha, W. I. (2001). Evaluation of handling systems for container terminals. *Journal of waterway, port, coastal, and ocean engineering*, *127*(3), 171-175.

Notteboom, T. (2012, May). Dock labour systems in North-West European seaports: how to meet stringent market requirements?. In *Proceedings of the International Forum on Shipping, Ports and Airports (IFSPA)*.

Peters, V., & Van de Westelaken, M. (2011). *Spelsimulaties - een Beknopte Inleiding in het Ontwerpproces (Simulation Games- A Brief Introduction to the Design Process)*. Nijmegen: Samenspraakadvies.

Saanen, Y. A. (2004). *An approach for designing robotized marine container terminals*. MSc. Thesis. TU Delft, Delft University of Technology, The Netherlands.

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., & Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European journal of operational research*, *233*(1), 1-15.

Turnbull, P., & Weston, S. (1993). The British port transport industry part 2. Employment, working practices and productivity. *Maritime Policy and Management*, *20*(3), 181-195.

Van Os, M. (2012). *Using gaming as a data collection tool to design rules for agents in agent-based models* (Doctoral dissertation, M. Sc. thesis. Delft University of Technology, The Netherlands).