On the Implementation of Simulation-based on Representation by Rules Methodology to Plan Port Logistics Operation

Anibal Tavares de Azevedo[a]
Applied Science School, University of Campinas, Rua Pedro Zaccaria, 1300, Limeira, Brazil

Keywords: Simulation, Port Logistic Operation, Representation by Rules.

Abstract: This paper proposes a fast and agile methodology that enables easy incorporation of different business rules for planning port logistics operations. The rules could be embedded in a simplified discrete-event and multi-agent simulation scheme that clearly shows the impacts of different rules in each part of the port operation. Furthermore, the developed approach enables an analysis of how operational decisions in one port could affect subsequent ports.

1 INTRODUCTION

The introduction of containers into commerce among countries enabled a higher degree of efficiency in supply chains. Although, uncoordinated port operations could lead to congestion or even worst supply chain disruption, as noted by (Loh and Thai, 2014): “The increased importance of ports makes them a vulnerable node as a port-related disruption can generate domino effect on a network of supply chains. The vulnerability of ports thus needs to be addressed to ensure the functionality of ports and enhance supply chain resilience.”

Furthermore, unpredicted events like Evergreen blocking Suez Canal could lead to a sudden increase in demand for port operations. According to (Leonard, 2021): “That is going to have a big impact on the already stressed supply chain”.

1.1 Solution and Literature Review

A solution to deal with such kind of unpredicted events, according to (Cholteeva, 2021), is: “Supply chains will have to be agile, nimble and flexible to counter problems like these. Overnight, batch-based processing and planning simply won’t cut it. Real-time, fully integrated and digitized supply chains are needed to reduce the impact of events like these to a minimum”.

The key concept to avoid uncoordinated port operations is the ability to fast adapt and react to unpredicted events considering all parts of the system (Zavala-Alcívar et al., 2020). Although, articles in literature integrate only some problems of container ports: berth allocation and quay crane scheduling (Bierwirth and Meisel, 2010; Yang et al, 2012); others integrate the allocation of berths and yard operation planning (Hendriks et al., 2013); and some integrate empty container allocation in the yard with vehicle routing (Braekers et al., 2013).

From previous articles, it is possible to see that integration is limited to propose specific models for one stage or a combination for a few of them. This could lead to planning without coordination among stages and some could behave as bottlenecks for the container flow through the port.

1.2 Contribution

The solution should encompass, as observed by (Zeng and Yang, 2009), the following: “Many complex systems such as manufacturing, supply chain, and container terminals are too complex to be modeled analytically. Discrete event simulation has been a useful tool for evaluating the performance of such systems. However, simulation can only evaluate a given design, not provide more optimization functions. Therefore, the integration of simulation and optimization is need.".

[a] https://orcid.org/0000-0003-1678-7795

Tavares de Azevedo, A.
On the Implementation of Simulation-based on Representation by Rules Methodology to Plan Port Logistics Operation.
DOI: 10.5220/0010602404380444
In *Proceedings of the 11th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2021)*, pages 438-444
ISBN: 978-989-758-528-9

In this sense, we developed a methodology to face random events and fast propose and evaluate a new set of decisions for all stages of a complex system like a container port is.

Based on simulation-optimization that employs representation by Rules for port logistics (Azevedo et al, 2018; Araújo et al., 2016, Azevedo et al., 2014) for one or two stages in a port, we created a general methodology, that could be easily adapted and employed in all container port stages through the application of four main steps:

Representation by Rules Methodology

I. Map agents, and their relations through the system process. Select agents that will be studied and the areas where they operate;
II. Describe all possible agent operations to complete a process. For each operation describe the rules that could be employed;
III. Combine rules into a hybrid simulation based on discrete event simulation and agent simulation;
IV. Test a different combination of rules and identify the one that should be adopted considering the best performance of the overall system.

The next sections will describe in detail how to employ this methodology for a specific part of a container port operation.

2 THE PROBLEM

The step (I) to employ the Representation by Rules methodology is to perform an adequate mapping of the relevant agents and their relations that enable the port processes.

In a container port, there are three main processes related to container flow: import flow (IF), export flow (EF), transshipment, or temporary flow (TF).

Figure 1 identifies the following port agents: container ship, quay crane, vehicle, yard crane, and yard storage blocks.

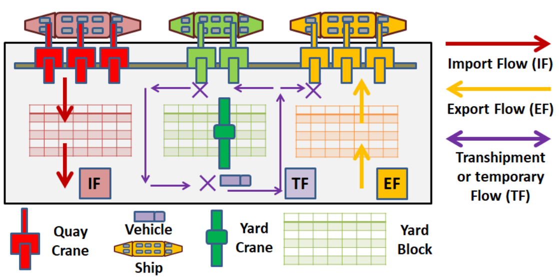

Figure 1: Container port agents and their relations.

Figure 1 also makes clear the relations among agents through three main processes. One example is that a quay crane will unload (IF or TF) or load (EF or TF) a container into a container ship.

Two agents will be selected to illustrate the methodology application: Container ship and quay cranes which operate at the berth area and quay area.

2.1 Selection of Agents and Stages

Step (II) consists of the mapping agent's cooperation to perform a process. In the context of a container port, ship unloading and loading operations could be described as done in Figure 2.

Some process constraints should be observed:

1. The container ship stowage plan: this is a ship map indicating where each container will be or is positioned inside a container ship;
2. Proper scheduling of two or more quay cranes should consider the movement of rail-mounted equipment, and keep a minimum distance to avoid collisions.

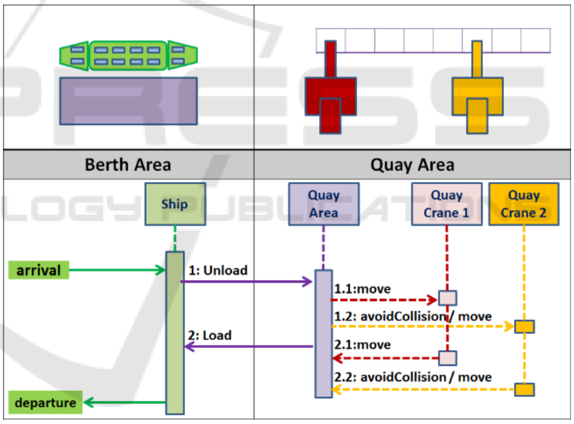

Figure 2: Container ship and quay crane cooperation to unloading and loading cargo process.

2.2 Creation of Agent's Rules

From Figure 2 it is possible to determine which rules could be related with agent:

1. Container ship:
1.1. Unloading rules (CUR): determine which containers should be unloaded. Two examples are: remove only the containers whose destination is the current port, or also remove more containers to reduce the number of future blocking containers.
1.2. Loading rules (CLR): should determine the position where a container will be stored.

Since containers on a ship are organized in stacks, depending on the position selected this could result in more or less blocking containers. A blocking container hampers a container that is downwards on the same stack and should be unloaded.

Figure 3 describes how the ship organizes containers in stacks. Furthermore, stacks are organized in pairs of odd bays (for containers of 20th feet) or even bays (for containers of 40th feet).

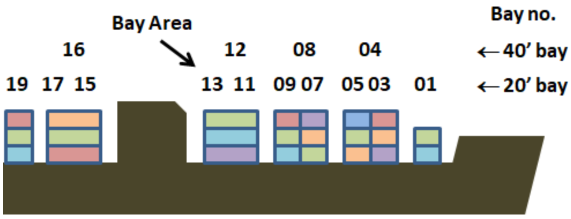

Figure 3: Arrangement of containers in a ship.

Figure 4 details the organization in the 13th bay in terms of rows and columns.

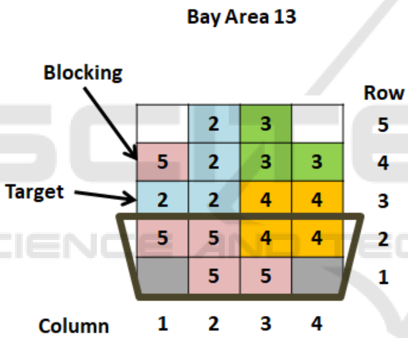

Figure 4: Arrangement of containers in 13th bay.

Each square with a number indicates that space is occupied with a container. The number inside a square specifies the destination port of a container.

Furthermore, Figure 4 illustrates the container in position (row, column) = (4, 1), which destination port is 5, is a blocking container. This occurs because, once the ship arrives at port 2, this container should be unloaded to allow the target container on position (3, 1) to be unloaded.

Once the container ship rules determine which containers will be moved in each bay, the total workload per bay will be computed. Then, quay cranes will employ rules to compute the total time necessary to perform all operations.

2. Quay cranes:

2.1 Initial position rules (QIR): determine which position is the more adequate to start the quay cranes work. No matter is for unloading, loading, or both operations on the ship.

2.2 Movement rules (QMR): should observe physical constraints like one quay crane could not overpass another one since they are rail-mounted, and should keep a secure distance to avoid accidents.

Figure 5 illustrates in detail two quay cranes allocation in terms of 20' bays workload.

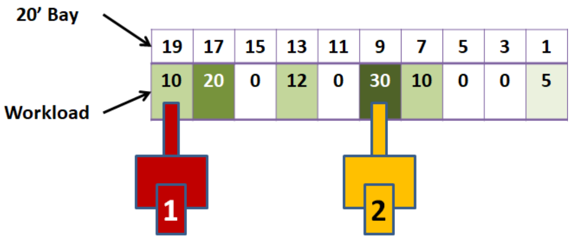

Figure 5: Initial position of quay cranes 1 and 2.

It is also important to stress that container ship rules consider the number of containers moved and quay cranes rules are related to the total time to perform movements. One manner to merge rules is to employ a simplified algorithm base on discrete-event simulation and multi-agent simulation.

2.3 Combining Rules using Simulation

Instead of using a complete simulation framework that encompasses discrete-event and multi-agent with a great computational burden, we created an algorithm that considers the main aspects of both paradigms with minimal coding. It is also important to stress that this scheme could be expanded and generalized for a higher number of agents (ships and quay cranes) or areas (Yard Area, for example).

Furthermore, the algorithm is a form of a function in which parameters are the rules that will be applied for an agent. The algorithm returns the total time necessary to perform specified operations. In this case, it means the necessary time to perform operations to unload and load containers in a ship in one port.

Another important aspect is that the container ship is represented by a vector of matrices B whose element values must be integer numbers representing the final port destination if space is occupied by a container, or zero if the space is empty. This matrix representation encompasses the ship organization of containers as described in Figures 3 and 4. The scalar p indicates which port is the current one. Vector TB indicates which blocking containers will be unloaded temporarily that will be reloaded with containers from the current port from vector TP. The vector VB is the total workload per container ship bay that will be used to compute the total time necessary to perform all unloading or loading tasks using quay cranes. The vector VB encompasses the scheme described in Figure 5.

```
Simulation(B, CUR, CLR, QIR, QMR)
Begin
 # Unloading operations.
 [B, VB, T] = unloading(B, CUR, p)
 Tmov = TotalTime(VB, QIR, QMR)

 # Loading operations.
 [B, VB, T] = loading(B, CLR, p)
 Tmov = Tmov + TotalTime(VB,QIR,QMR)

 return Tmov
End
```

2.4 Testing Combination of Rules

Figure 2 describes each agent operation to ensure that the unloading and loading cargo processes will be done. These processes could be related to agent rules as done in Table 1.

Table 1: Agents, their operations, and related possible rules.

Agent	Operation	Rules
Ship	Unload	CUR1, CUR2
	Load	CLR1, CLR2
Quay Crane	Initial position	QR1, QR2
	Move	
	Work	

For ships, there are two sets of possible rules: unloading and loading rules in the sense detailed in subsection 2.2.

For the cranes, although there are three possible operations it is possible to create just one set of rules. This could be done for the following reasons:

A. Quay crane movement is restricted to be one-directional without losing the possibility to achieve an optimal solution (Chen et al., 2014); Furthermore, movement rules (QMR) described in subsection 2.2 will be followed;

B. Quay cranes are assumed, without loss of generality, to be equal and with a deterministic processing time.

From (A) and (B), the only difference between quay cranes will be the decision on the initial position of each quay crane.

Since the set of rules for each operation is defined, the decision problem could be simplified to choose the best combination of rules that will produce the minimal container ship stay time in port. Tables 2 and 3 give the eight possible combinations of rules for the set of rules described in Table 1.

Table 2: First four possible combinations of rules.

Combination	Unloading	Loading	Crane
1	CUR1	CLR1	QR1
2			QR2
3		CLR2	QR1
4			QR2

Table 3: Last four possible combinations of rules.

Combination	Unloading	Loading	Crane
5	CUR2	CLR1	QR1
6			QR2
7		CLR2	QR1
8			QR2

Tables 2 and 3 could be summarized in terms of sequences of numbers as done in Table 4.

Table 4: Summarizing Table 2 and 3 in terms of numbers.

Combination	[1, 2, 3, 4, 5, 6, 7, 8, 9]
Unloading	[1, 1, 1, 1, 2, 2, 2, 2]
Loading	[1, 1, 2, 2, 1, 1, 2, 2]
Crane	[1, 2, 1, 2, 1, 2, 1, 2]

One important computational aspect is how to use combination numbers to determine which rule should be applied. For this purpose, Equation (1) is useful.

$$\text{(math.floor(i/N))} \,\%\, M + 1 \tag{1}$$

where: i is an integer number, N is the number of repetitions of the digit that belongs to the set {1, …, M}.

From Equation (1) is possible to convert the numbers on the combination sequence into other sequences:

I. Unloading sequence: N = 4 and M = 2 will produce: [1, 1, 1, 1, 2, 2, 2, 2];
II. Loading sequence: N = 2 and M = 2 will produce: [1, 1, 2, 2, 1, 1, 2, 2];
III. Crane sequence: N = 1 and M = 2 will produce: [1, 2, 1, 2, 1, 2, 1, 2].

This encoding helps to provide the following function that translates an integer number (from combination sequence) into other sequence numbers.

```
def translateNum2Rules(i,nrules):
  nr = len(nrules)
  x = [0]*nr
  for t in range(0,nr):
    N = np.prod(nrules[0:t])
    I = (math.floor(s/N)) % nrules[t]+1
    x[t] = i
  return x
```

3 SIMULATION EXAMPLE

Consider a simplified version of a ship with an initial cargo, for didactic purposes, are as shown in Figure 6.

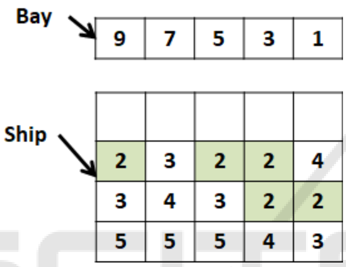

Figure 6: Simplified container ship.

The combination of rules that will be performed is 1 which means, according to Table 2, CUR1, CLR1, QR1.

Since the container ship arrived at port 2, it is necessary to unload all import containers with the number 2 and ones that are blocking its movement (CUR1).

Another unloading rule could consider removing all containers that could be blocking containers as the container 3 in bay 1 (CUR2).

Observe that the unloading rule will generate the workload output for quay cranes operation.

To remove containers from the ship two quay cranes will be employed using the QR1 rule which initial position in bays will be the one presented in Figure 7.

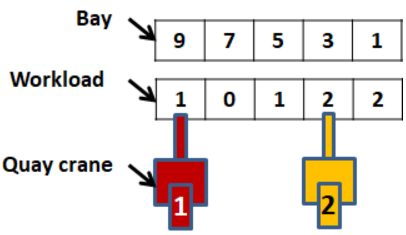

Figure 7: Initial position using QR1.

Considering that quay cranes could work in parallel without a collision and the time necessary to move one crane to another bay is one workload time, then the total time to perform unloading operations will be 5 units of time.

The next step is to plan the spaces on the ship where export containers will be loaded. Suppose that the number of containers for each port destination is as detailed in Table 5.

Table 5: Export containers in port 2.

Destination	3	4	5
#	2	2	1

Additionally, the blocking container, which destination is port 4, that was moved during unloading of container 2 in bay 1, are already counted in Table 5.

The loading rule chosen for the next step is CLR1 which means start to search for a position in ship containers with the lowest port destination (3). The position should avoid producing blocking containers and begin from the bay with the lowest number to highest number filling as shown in Figure 8.

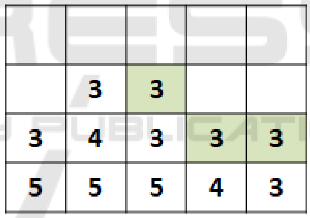

Figure 8: Future ship arrangement after loading containers to port 3.

Now the containers which port destination is 4 will be distributed along bays, but they turn to be blocking containers as shown in Figure 9.

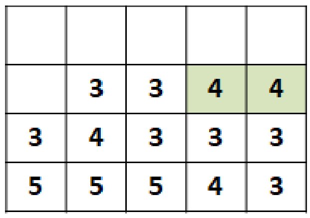

Figure 9: Future ship arrangement after loading containers to port 4.

Finally, the position for the container to port 5 is also determined.

5	3	3	4	4
3	4	3	3	3
5	5	5	4	3

Figure 10: Future ship arrangement after loading container 5.

After determining all positions of containers that will be loaded, the workload per bay is computed and will be the same as shown in Figure 7. As a result, the total time to perform loading operations will be 5 units of time. Another combination of rules, like one with LR2 which is the reverse of LR1, could lead to another total stay time value.

The process to choose the best combination is to evaluate all possible combinations and pick the one with the lowest total stay time for the ship. Although, this task could be a computational burden task for a decision in multiple ports as shown in Section 4.

4 EXTENDING FOR MULTIPLE PORTS

Section 3 showed how to evaluate one possible combination of rules using a simulation that produced total time to perform operations in one port.

Additionally, the methodology could be applied for all ports that a ship will pass during its travel. Figure 11 explains how to do an integrated evaluation for more than one port.

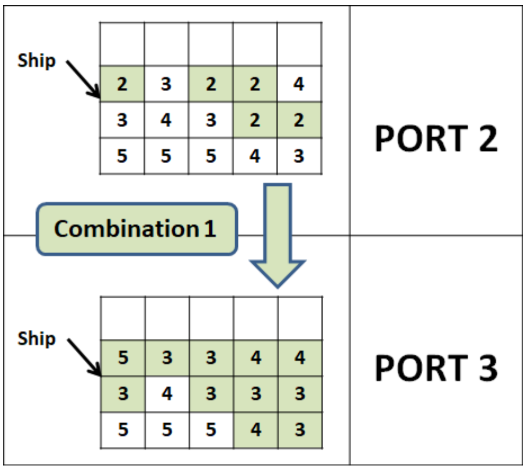

Figure 11: Extending the methodology for more than one port.

Employing the combination of rules 1, as described in section 3, the container ship arrangement will change after port 2 as shown in Figure 11.

The extension made in Figure 11 could be replicated between ports 3 and 4, and ports 4 and 5. By doing this, it is possible to measure the impact of chose different rules through several ports.

Although this extension is interesting for a more detailed evaluation it will bring more complexity to simulate all combinations of rules as will be shown in Section 5.

5 MULTI-PORT OPTIMIZATION PERSPECTIVE

Section 4 showed how to evaluate a solution for several ports. A general representation that enables the test of several combinations of rules is shown in Figure 12.

Comb	1	1	1	1	1
Port	1	2	3	4	5

Figure 12: Using rules for more than one port.

In Figure 12, only the combination of rules 1 was applied for every port. It is important to stress that this is one possible combination in 5^8 = 390.625 alternatives of combinations.

Furthermore, as the number of agents and operations increases, the search for an optimal combination of rules could be a computational burden task.

One possibility is to employ flexible methods to deal with combinatorial problems like metaheuristics as genetic algorithms, for example (Azevedo et al., 2014; Azevedo et al. 2018).

6 CONCLUSIONS

We extended the representation by rules approach to be a methodology to tackle any port process related to any agent with its corresponding operations.

Furthermore, we illustrated how this approach could be used to evaluate, for example, the total time that a container ship will take to perform all unloading and loading operations through ports.

Ideas of future works are:

- It could all be extended to consider more port agents and their operations in more stages like the Yard (Zhen et al., 2013) ;

- The proposed simulation modeling could be coupled with an optimization tool for a combinatorial problem on a simulation-optimization scheme;
- An automatic generator of rules could be created for each operation;
- A Monte Carlo approach could be incorporated to tackle uncertainty on demand variation.

REFERENCES

Araújo, E. J., Chaves, A. A., Salles, L. L. N., Azevedo, A. T. (2016). Pareto clustering search applied for 3D container ship loading plan problem, *Expert Systems with Applications*, 44, 50-57.

Azevedo, A. T., Ribeiro, C. M., Sena, G. J., Chaves, A. A., Salles, L. L. N., Moretti, A. C. (2014). Solving the 3D Container ship loading planning problem by representation by rules and meta-heuristics, *International Journal of Data Analysis Techniques and Strategies*, 6(3), 228-260.

Azevedo, A. T., Salles L. L. N., Chaves, A. A., Moretti, A. C. (2018). Solving the 3D stowage planning problem integrated with the quay crane scheduling problem by representation by rules and genetic algorithm, *Applied Soft Computing*, 65, 495-516.

Bierwirth, C., Meisel, F. (2010), A survey of berth allocation and quay crane scheduling problems in container terminals, European Journal of Operational Research 202 (3), 615 – 627.

Braekers, K., Caris, A., Janssens, G. (2013) Integrated planning of loaded and empty container movements, OR Spectrum 35 (2), 457–478.

Chen, J., Leeb, D.-H., Gohc, M., (2014) An effective mathematical formulation for the unidirectional cluster-based quay crane scheduling problem, European Journal of Operational Research, Vol. 232, No. 1, 198-208.

Cholteeva, Y. (2021). Offshore explainer: The Evergreen Marine blockage at the Suez Canal, *https://www.offshore-technology.com/features/offshore-explainer-the-evergreen-marine-blockage-at-the-suez-canal/*, 26th, March.

Hendriks, M. P. M., Lefeber, E., Udding, J. T. (2013) Simultaneous berth allocation and yard planning at tactical level, OR Spectrum 35 (2), 441–456.

Leonard, M. (2021). Ever Given and the Suez Canal: A list of affected ships and what delays mean for shippers, *https://www.supplychaindive.com/news/ever-given-suez-canal-evergreen-blocked-shippers-cargo/597295/*, 21th, March.

Loh, H. S., Thai V. V. (2014). Managing Port-Related Supply Chain Disruptions: A Conceptual Paper, *The Asian Journal of Shipping and Logistics*, 30(1), 97-116.

Yang, C., Wang, X., Li, Z. (2012) An optimization approach for coupling problem of berth allocation problem and quay crane assignment in container terminal, Computers & Industrial Engineering 63 (1), 243–253.

Zavala-Alcívar, A., Verdecho, M.-J., Alfaro-Saiz, J.-J. (2020). A Conceptual Framework to Manage Resilience and Increase Sustainability in the Supply Chain, *Sustainability*, 12, 6300, 2071-1050.

Zeng, Q., Yang, Z. (2009) Integrating simulation and optimization to schedule loading operations in container terminals, Computers & Operations Research 36 (6), 1935–1944.

Zhen, L., Jiang, X., Lee, L.H., Chew, E. P. (2013). A Review on Yard Management in Container Terminals, Vol.12 No.4, pp. 289-305, *Industrial Engineering & Management Systems*, Korean Institute of Industrial Engineers.