A SYSTEM DYNAMICS APPROACH FOR IMPROVING CONTAINER TERMINAL OPERATIONS

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ABSTRACT

This study provides a simulation based framework for the optimal integration of the various activities within a container terminal. The operation of a container terminal is made possible thanks to the interaction of numerous subsystems, which, in turn, depend on other subsystems. Indeed the performances of the container terminal are affected by many factors such as component subsystems of the whole system, equipment, resources and procedures. In order to represent the relation between these factors, a System Dynamics approach is proposed. This approach tries to explain: 1) the interactions between all subsystems of the system; 2) the effect of any changes of their factors to the global performance.

This study aims to provide management tools to control performance of each subsystem and of the whole system and to anticipate the effect of performance improvement of subsystems on the whole system. The choice of utilizing a SD paradigm derives from the possibility of studying through a casual loop diagram the relationships between all variables involved and the effect of any changes of these factors on the each subsystem's performance and on the whole performance by means of a simulation model.

Keywords: System Dynamics, container terminal operations, simulation

1. INTRODUCTION

A container terminal is an open system of material flow with two external interfaces: seaside interface and landside interface. It consists of four functional subsystems connected together:

- 1. Gate area or landside. This area can be divided into import gate and export gate. Through the export gate, full trucks enter into the yard for unloading the containers. The import gate is dedicated to empty trucks coming into the terminal for picking up cargos.
- 2. Seaside is a space where the vessel can anchor for unloading/loading cargos. When unloading or loading cargos, an equipment called quay crane is used.

- 3. Interconnection area: this functional area is composed of equipment to transport containers between the seaside and the stacking area and vice versa.
- 4. Stacking area: this area can be divided into import and export yard. In order to unloading or pick up containers, trucks enter into export or import yard and drive to the assigned location where reach stackers or rubber tired gantry (RTG) unload or load the cargo. The yard equipments unload the cargo from the quay or handle the containers to load into the ship.



Figure 1: The physical flow of a container terminal.

The physical flow follows these interconnected steps:

- When a container ship reach the port, if a suitable terminal's quay is available, then the container ship enters the berth or waits at the anchorage.
- Container ships wait for service on the berth. If there are idle quay cranes the container ship is unloaded and/or loaded.
- Container trucks transport the container to the yard or to the quay. If there are idle quay cranes and/or yard cranes, empty tugmasters receive containers and move them to corresponding locations.

Therefore, the container terminal operations are:

- Receiving operation
- Delivery operation
- Loading operation
- Unloading operation

The productivity of a container terminal can be measured in terms of productivity of two type of operations. One type is the receiving and delivery operation, in which containers are transferred to/from external trucks. The other one is ship operation, in which the containers are unloaded and loaded from/onto the ships. Both types of operations are affected, in turn, by all internal operations, such as quay crane's operations, transfer operations between quay and yard and vice versa, and the yard operations.

2. MODELLISTIC APPROACHES IN LITERATURE

A container terminal is a dynamic and complex system where different operations have to be carried out. In fact it is characterized by highly complex subsystems that involve numerous equipments, operations and handling steps.

In literature different types of study have been proposed to model the operations in a container terminal. Different approaches are focused on modeling single operations or sequences of operations. However, most of the existing literature considers the optimization of a single subsystem of handling equipment, mainly in the scheduling quay cranes, cargo handling systems. These studies emphasized that each single problem, related to an operation, has to be considered as a part of the whole system and it has to be individually optimized in order to improve the whole performance. The operational problems considered are:

- Berth allocation;
- Loading and unloading of the ship: crane scheduling, stowage and unloading plane;
- Transfer of container from quay to storage area and vice versa;
- Stacking of container, scheduling of yard crane;
- Picking up of containers from export trucks;
- Delivery of containers to import trucks.

Many previous research studies on crane's scheduling treat the quay cranes separately from other resources in the terminal. For example, Kim and Kim (1999 a, b) consider the optimization of the routing of a single transfer crane in a port container terminal. The problem is formulated as a mixed integer program, and exploited in an optimization algorithm that uses dynamic programming.

Ascheuer et al. (1999) consider the scheduling of a stacker crane in an automated warehouse. The problem was modeled as an Asymmetric Traveling Salesman Problem (ATSP) and both heuristics and an exact Branch and Cut algorithm are used to solve the problem.

Meersmans and Wagelmans (2001) made a first integrated scheduling for QCs, AGVs, and automated stacker cranes (ASCs) in automated container terminals. They present a branch and bound algorithm and an heuristic beam search algorithm in order to minimize the makespan of the schedule. In a related research by Meersmans and Wagelmans (2001), an optimizationbased beam search heuristic is proposed to solve the integrated scheduling problem in a dynamic environment. However, in both static and dynamic cases, only the vessel loading operations are considered. Most of the literature considered the scheduling of a single type of equipment. However, the container terminal subsystems are tightly interrelated, optimizing only one subsystem may not necessarily yield an overall optimal terminal operation.

In the last decade, researchers have started to focus on the simultaneous optimization of quay cranes and other subsystems. Therefore, to improve the productivity of a container terminal some studies focused on scheduling of different types of handling equipment in an integrated way. In this way, the operations performed by the container handling equipment at container terminals are interrelated to each other.

The latest studies (also our study) are focused on modeling the whole system under the point of view of interconnected and synergic subsystems. Considering the whole system, the problem complexity grows up because many problems are linked by shared resources, whose availability are time dependant, and their interconnections have affect on the whole performance. Therefore, the container terminal can be considered a "system of systems" for its complexity, because it is composed of a set of different subsystems with their specific goals. These subsystems, totally or partially, share some resources with fixed capacity in order to ensure the whole system functioning.

The import and export flows are the result of the interaction of the aforesaid four subsystems. Each subsystem is itself a complex system. The individual subsystems are different and can partially operate in an independent way, but their proprieties and interactions type affect the whole system performance.

Furthermore there are different interrelated performance indicators for each functional area of a container terminal, each measuring the productivity and utilization of each resource. The quay crane throughput can be considered the global performance indicator of a container terminal, because it is affected by the productivity of each subsystem. There are many different decisions involved in operating a container terminal and all these affect each other, affecting indirectly the efficiency of quay cranes.

Therefore it becomes clear that the interactions and synergy of these subsystems affect the global performance because the global performance is not only the sum of the performance of each subsystem.

Given the complexity of the "system of systems", as a container terminal, Systems Dynamics is a suitable

approach to analyze the feedback loops, the interactions between subsystems and the temporal delays. Therefore, through a dynamic and experimental approach it is possible to synchronize the subsystems in a global view perspective.

In order to analyze all interactions between subsystems it is necessary to define a conceptual model of the whole container terminal, where quays, yards, gates and transfer systems can be considered as resources. The corresponding simulation model can be used to phase all subsystems and to define their optimal configuration in a system perspective. In fact, considering a container terminal as a whole, the throughput is determined by individual capacity of each component, such as vessel berthing, vessel unloading /loading, container's transfer from quay to yard and yard to quay, yard storage and gate passage. But it is generally equivalent to the lowest capacity of each of these and it is also influenced by their interactions The occurrence of waiting times in different points throughout system is dependent on the variability of service times of each stage of the process and the different cycle time of the resources involved.

2.1. A Casual Loop Diagram for container terminal operations

The relationships between the various subsystems of a container terminal can be effectively represented through a Causal Loop Diagram (CLD, figure 2). The process of loading (and unloading) of containers from vessel to the container yard and vice versa uses three kinds of equipment: container quay crane, tugmaster and yard equipment (Rubber Tired Gantry for import area and reachstackers for export area) by working in a synergy, so the process of loading and unloading of each container from vessel to the container yard and vice versa depends on harmony of the above mentioned equipment. However, the unevenness of cycle times of these equipments causes often the lack of this harmony and their optimal synergy. Indeed, the speed of loading and unloading process depends on the Berth Occupancy Rate and on the capacity of the resources, but it is also related to the activities of transfer, storage and retrieval that take place into the yard. The lower part of the CLD shows the loops that characterize the subsystems and their interrelations.

In the upper part of the CLD there are several interconnected loops (figure 2). In fact, the waiting time of the ships entering the harbor is influenced by the activity of containers loading and unloading, because a ship can be moored only if a second pier is available or if the loading/unloading operations on the previous ship have been completed. Moreover, a loading and/or unloading process slower and/or a high amount of containers to be handled produces a long ship Turnaround time (TRT) and a greater Pre-Berthing Time for the next vessel, implying a reduction of the ships served. The number of ships served and quay availability are linked by a negative cause-effect relationship, in fact the increase of quay availability produces the decrease of waiting time for ships. Thus, the number of moored ships increases with the decrease of the waiting time. On the other side, an increase in the number of containers to be handled involves a greater utilization of the resources of terminal, such as quay, transfer system and yard.

The lower part of the CLD (figure 2) shows the internal loops of each subsystem and also the interactions between all subsystems:

1. Quay cranes subsystem.

The cycle time of quay cranes in loading and unloading process is influenced by many variables, such as human resources, the number of cranes in operation (crane scheduling for single bay of the ship) and also by external variables, like the availability of tugmaster under the crane.

2. Transfer subsystem

The process of containers transfer from the quay to the yard and from the yard to the quay is affected by internal variables of the transfer system, such as the number of tugmasters (a variable connected to the number of operative crane), the ability of human resources involved, and also by external factors like the level of congestion in the yard for storage and retrieval operations.

3. Yard subsystem

The cycle time for containers handling (import and export flow) is influenced by the quality of human resources, by the overlapping of quay and gate activities and tugmasters delays.

Therefore, the upper part of the CLD shows the loops connected to the global system, while the lower part reports the loops characteristic of subsystems and their interactions. Considering these loops, the overall optimization of a container terminal does not depend on separated optimization of its subsystems, as the overall performance is not simply the sum of the performance of its components. In fact, increasing capacity of a subsystem may improve its performance but providing a negative effect on those of other components, and even have a negative impact on the overall dynamics of the terminal.



Figure 2: Casual Loop Diagram for terminal container operations.

2.2 Case study

The general CLD reported above has been applied to a real case in order to be validated. The container terminal considered handles containers loading -unloading with the wharf lengths of 315 and 295 meters, meaning that maximum two ships can be served at the same time. On the bigger quay there are 4 quay cranes while on the smaller one there are 2 cranes, but the number of operative quay cranes depends on the container stowage plan. When the vessel is anchored, the unloading and loading process can start. In order to transfer container from wharf to yard and vice versa, three tugmasters are assigned for each operative quay crane according to gang modality. The yard area is divided into import and export area according to a static strategy of space allocation. Summing up, the equipment involved in the terminal are:

- 2 quays with different length and draft and each of these is able to serve only one ship at once;
- 6 quay cranes, their function is unloading container from ships to the available corresponding tugmaster or vice versa;
- 10 Rubber Tired Gantries (RTG) in the import yard involved in stocking containers transported by tugmasters and delivering containers to trucks coming from the gate
- 9 Reach Stacker in the export yard. Two of them are assigned to export trucks while the others are assigned one for each operative quay crane;

• 15 tugmasters to transport containers from wharf to container yard or vice versa.

3. SCENARIO ANALYSIS

Based on the interconnected mechanism, shown in the CLD, we developed a simulation model of the terminal container considered. First of all, we run some experimental tests in order to validate the model. Then, we used this model to evaluate possible shortages or surplus of capacity for available equipment. In addition, we identified the system's components on which to intervene in order to optimize the capacity of equipment available. Several models have been developed each corresponding to different real system's configurations. The first model describes the current situation and the others allow to analyze possible interventions on elements that have significant influence on the global performance.

Several assumption have been adopted in constructing and implementing the improvement plans for our container terminal. In particular, the equipment configuration scenarios used are:

- Scenario I (SI), existing condition.
- Scenario II (SII), adding 1 tugmaster for each operative quay crane.
- Scenario III (SIII), reducing of 1 unit the number of tugmaster for each operative quay crane.
- Scenario IV (SIV), using also in the import yard the same strategy used in the export yard. Considering one operative RTG corresponding to each unloading quay crane.

As an example of the output from the models, we consider the quay cranes productivity, i.e. the number of container moved per hour. Through an experimental valuation we derived that the optimal number of tugmaster assigned to each loading /unloading crane is the current number, 3, indeed a lower number of tugamasters would cause a reduction in quay cranes productivity, while an higher number would determine the same performance. Basing on these considerations, we could conclude that resources' sizing and composition is already optimal, therefore the problem is the interference between quay and gate services. The Scenario IV, therefore, propose a new resource management strategy able to separate the gate and quay activities.

4. CONCLUSION

This study proposes a systemic approach to analyze the operation of a container terminal. The container terminal has been considered as "a system of systems", composed of complex subsystems. By taking into consideration the causal loop relationships between its components, the optimization of each subsystem does not provide the overall optimization of the system, in fact an increase of subsystem's performance may provide a negative effect on the behavior of other components and on the overall dynamics of the terminal.

Using a systemic approach it is possible to analyze the internal dynamics of the container terminal depending on changes made to the initial conditions. The internal process of the container terminal has been exploded through internal causal loops.

This study has also led to develop several simulation models to analyze the operation of a specific terminal container and to point out the dynamic internal changes of the terminal components corresponding to different scenarios for terminal operation. However, these models have been developed to emphasize the causal relationships existing within the system and in which measure these connections contribute to the overall terminal container operation.

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