MODELS FOR SUPPORT MARITIME LOGISTICS: A CASE STUDY FOR IMPROVING TERMINAL PLANNING

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KEYWORDS

Simulation, Berth Management, Container Yards, Optimization, Linear Programming

ABSTRACT

Container terminals world wide are trying to expand capacity and increase performance at a minimum of investments. Often the container terminal operations are changing to meet increased customer demands as well as to adapt to new technologies. The increasing costs of container terminal development do justify the use of computer simulation to assist in planning and policy making. The use of specific mathematical models for supporting yard operations optimization is turning to be the key of the next generation Decision Support Systems, the paper outline the integration between a flexible simulator which represents the marine-side operations of a container terminal with a Linear Programming model for improving berth assignment management polices and yard stacking management policies.

INTRODUCTION

In the last years maritime transport shown an outstanding growth, causing to some harbors to reach their maximum capacity limits and so simulation gain, consequently, interest as primary methodology to proper address the upcoming years challenges..

Another important aspect is the radical changing in the Supply Chain where Europe and the Western Countries are going to change their position from mostly exporting to importing area due to the growing in outsourcing towards Far East countries like China and India.

This change involves also the logistics structure of the harbors moving from, basically, handling and storage facilities towards an Integrated Multimodal Terminals in which the goods are sorted, routed and, eventually, transformed to finished goods. The challenge of increase the port traffic avoiding to paralyze the harbor itself and its accessing ways is turning to be the critical point of the new development strategies for the upcoming years.

In the past modeling & simulation was used as base methodology for improving port operations, yard planning and resource control in such way several experiences can be capitalized and new approaches can be designed based on it .

Several simulation projects were developed, in fact, to optimize the scheduling policies of the terminal in order to reduce the waiting times and improve the overall performances. In such field techniques used ranging from discrete event models in order to study the advantages of an automated container terminal (Delft University in Netherlands), to the use of a specific model for simulating sea conditions and their effect on the maritime logistics (University of Ulster) up to Petri Networks (University of Barcelona, Spain).

Some recent studies made by the Dong-A University of Korea demonstrated also the advantages of an ERP-like approach in container handling for reducing the system development time, eliminating redundancies, maintaining integration and enabling flexibility, standardization of workflow.

Starting from the authors experiences in design and implement Decision Support System (DSS) devoted to optimize logistics of maritime transportation the authors propose an innovative approach based on the integration among Discrete Event Simulation and Linear Programming to improve the effectiveness of the yard schedule by validating traffic forecasts with credible simulation scenario. Genoa Port, particularly, starting from an high percentage of empty containers (i.e. about 35% in 2003 versus the 20% of Rotterdam Port) can be regarded as the proper case study for the proposed methodology.

The idea and the goal of this paper is to optimize the sequence of loading and unloading operations focusing on the wharfs' occupation considering all the factors, controllable and not controllable, involved in the berthing process in order to reduce inefficiency and improve the potentials of the terminal.

The factors involved in this approach are the stochastic process of the incoming ships, sea conditions, and the consequent extra costs due to additional wharf occupation for improper dock schedule. Constrained

Proceedings 19th European Conference on Modelling and Simulation
Yuri Merkuryev, Richard Zobel, Eugène Kerckhoffs © ECMS, 2005
ISBN 1-84233-112-4 (Set) / ISBN 1-84233-113-2 (CD)

resources (i.e. crane drivers, loaders, berth operators, cranes, stackers, transtainers, forklifts, tugboats and container yard) were considered in the proposed study.

SIMULATION FOR MANAGING TERMINALS AND PORTS

Simulation in maritime environments has been developed by the scientists for a long time, in fact both the authors themselves and other researchers had studied technologies devoted to improve performances inside an harbour and on the infrastructures around it (railroads, motorways, etc.).

The authors took care of this aspects since 1996, when the first project regarding the use of Virtual Reality devoted to train Service Operators inside Genoa Port and then to improve safety, called "Safety First", was implemented by Liophant Simulation, after that, they continued to use simulation in order to improve port operations; in fact in 2002, during the TransBaltica 2002 Conference, POSEIDON simulator was implemented in order to study the behavior of an Oil Terminal in Genoa at the arriving of several types of tugs pilots and boats and to manage the docks and its resources in order to reach the goal of the best performance.

Other important works, developed principally in the years 2002-2003,at the 18th International Port Conference of Alexandria in Egypt in 2002, in fact, was presented an innovative work by the Dong-A University in South Korea devoted to manage Container Terminal Operating Systems using an ERP Approach, clustering for example the workflow of the container terminals, analyzing the business process to generate the best workflow and using the planning facility, coupled with data flow from client entities such as shipping companies.

In 2002 was developed the TOMAS project, a tool for Object-Oriented Modeling and Simulation created two years before by the researchers of the Delft University in Netherlands, applied in an automated Container Terminal, that guarantees the advantages of the stand-alone complex model divided into small sub models easy to understand and an improved transparency and maintainability of the simulation model.

During the International Conference HMS & MAS 2002, held in Bergeggi, Italy, the University of Barcelona, Spain, presented a modelling methodology based on Coloured Petri Nets (CPN) formalism to design a software tool useful in port process simulation in order to make easier the design and the management of port terminals.

The next year (2003) in Alexandria, Egypt was presented a system of PDGPS (Precision Differential Global Position System), applied in the Gantry Cranes in Alexandria Port, in order to increase and improve the Yard Productivity to match today's Ship To Shore Crane Productivity tracking the Containers and using Auto Steering tools for cranes.

Another application, called SIRIO; was presented as a DSS (Decision Support System) in harbor operations using Web Based Distributed Simulation in a Java, based architecture able to share quantitative models among Internet and Intranet for helping decision makers using Autonomous Agents (AA).

The researchers of the Limburg University Central in Belgium, instead, developed an heuristic algorithm in order to find the best sequence of placing vessels inside a lock for harbours set in a river or in a canal, which are sometimes subjected to tides and other bad conditions.

Always in 2003 were presented works about the production of a software helping to manage port operations, one of them is the "Port Process Simulator" (PPS) developed by the Ulster University and already installed in three ports of the Baltic Area, which simplify all the harbouring activities.

In the same conference, HMS 2003 in Riga, Latvia, a real application of this software was presented for the Gdansk port, in Poland, and a possible scenario of further developments was shown, after a phase of VV&A (Verification, Validation & Analysis), by the simulator fed by the real data.

So simulation in harbours, both maritime and fluvial, it is one of the most active fields of the research in modeling and simulation.

THE IMPLEMENTED SIMULATION MODEL

The idea of this work is to find a strong solution even not necessarily the best performing for managing the ships arrivals timetable inside an Italian port container terminal.

The estimated time of arrivals of every single vessel is scheduled inside a DB (Database) calculating the "Delta" of the hypothetic arrival time versus the current time.

The real time of arriving is calculated taking into account several coefficients related to different events and using a Monte Carlo methodology; the most important factors are the quality of the data, the sea condition coefficient, that is bigger when the condition of the sea are worse and inflates the "Delta" between prediction time and real time and the distance between prediction and events themselves. The sum of these factors determines a coefficient that returns the delay of the ship arrival versus the prediction made inside the database.

Inside berthing operations it is obligatory to distinct the status of the jobs: some of them have a fixed position, which is not allowed to delay, while others are "free" and are classified with a priority index based on the customers' criticality (using for example an ABC analysis) and/or on the Due Date.

This work is also devoted to simulate the resources' utilization in a stochastic environment based on a priority index that determines the operating sequence, except for the operations already started, which is fixed and deterministic; inside there different scenarios are simulated using a system of stochastic rules to be evaluated in terms of strength, which is the goal of the entire scheduling process.

The model used for simulation is a discrete event one and it aims to be an useful tool for supporting planning of a great reality inside Italian maritime ports with container terminals: La Spezia Harbor; the model is quite simple and for its implementation it was preferred an higher speed of computation rather than a better precision.

Conceptually the idea is to divide all the operations in tasks, which are the elementary work units and so they are the leafs of an hypothetic tree of the operations; every task requires the work specialization and the availability of the resources allowed to do this task; every task is inside a well defined sequence with a well defined order of priority and it has a known (in stochastic terms) length, which is at least 1 hour or 1 day (8 hours).

The sequence of a group of tasks defined before is called "job", and it is the next level of the operations' tree, the tasks of a job are ordered with a strict sequence of priority and they are often grouped by workers' specializations (preparation, loading, unloading, moving…)

Inside this project are also defined the workstations, which are the descriptions of the available resources in order to run a certain number of simulation replications.

In order to sequence the activities at their best it is also provided to use an optimization algorithm well known in the field of the Operative Research, the "2-Opt Algorithm".

COMBINING SIMULATION AND MATHEMATICAL PROGRAMMING

One of the most important aspects in the maritime terminal management is related to the yard planning and to the internal traffic in order to reduce leadtime of incoming and outcoming goods. This point is even truer in container terminal where space and movement procedures plays an important role. One of the most interesting techniques used to proper solve this problem is based on Modeling & Simulation (M&S) where the entire terminal is modeled in order to find bottleneck and to test the effect of the upcoming and outcoming ships. This methodology is extremely expensive and time consuming since requires an intensive modeling effort that has to be continued in the life of the terminal in order to ensure proper representation of the reality. In other words simulation is sometime used only to solve some particular problems (i.e. yard management, docking/undocking procedures) and only in a very few case employed as a general methodology for the proper management of the entire terminal. This paper outline an approach in which simulation still play an important role remaining, at the same time, the principal test bed of the terminal management strategies an tactics rather than became the sole driver.

Since simulation is, basically, a what if technique isn't able alone to propose innovative solutions to the managers but helps to better evaluate their decisions. Only by combining it with Response Surface Methodology (RSM) a quest for a better solution can begin and, in this sense, simulation can play a crucial role.

In real life application, in fact, simplified models are used to rough cut first tentative solution that have to be tested under uncertain constraints in order to be declared effective. Classical mathematical solutions, such as Linear Programming and/or Theory of Constrains can be regarded as base approach for specific allocation problems such as a Yard Planning. Still one point remain on the table: how robust is the solution? In this way simulation is used to test solutions for their highest robustness by using DOE (Design of Experiment) and RSM policies and practices can now be set to their maximum robustness by investigating the role of their "parameter" to the appropriate objective function.

The proposed methodology starts with a Mathematical Model for supporting Berth Planning able to identify the correct place (space) for berthing a ship and the correct instant (time) to carried out this operation, this part of the problem resolution take, as input, the optimal position of the berth for each ship, that is, for our purpose, the nearest docking place where the containers have to be taken or dropped. In this way any choice made in the direction of planning the container yard has is effect on the Berth Planning that is optimized by using an appropriate model.

In the berth planning, we try to minimize the penalty cost resulting from delayed departures of vessels and the additional handling cost resulting from deviation of the berthing position from the best location on the berth. Carriers usually inform the expected arrival time and the requested departure time of vessels to the terminal operator. Based on the information, a terminal operator tries to satisfy the requested departure time of each vessel. However, when the arrival rate of vessels is high or unexpected arrivals occur, it may not be possible to service all of the vessels before the service completion time that they requested. Thus, departures of some vessels may be delayed over the requested due time. Note that the terminal operator has different priorities for different types of vessels. The priorities can be converted into weights (c) on the penalty cost of vessels in the objective function.

By considering the following notation is possible to express the Berth Planning problem in the form of a Linear Programming model, in particular let be:

N = The total number of vessels.
L = The length of the berth.
p_i = The best berthing location of vessel i-th.
This location is represented by the x-coordinate of the leftmost end of the vessel and determined considering the distribution of containers already arrived or a designated location for a specific vessel. The reference point for x-coordinate is the leftmost boundary of the berth
x_i = The berthing position of vessel i-th (a decision variable).
y_i = The berthing time of vessel i-th (a decision variable).
a_i = The estimated arrival time of vessel i-th.
d_i = The requested departure time of vessel i-th.
b_i = The requested time for the ship operation for vessel i-th.
This value includes the requested allowance between departure of a vessel and berthing of another vessel.
c_{1i} = The additional travel cost per unit distance for delivering containers of vessel i-th resulting from deviation of berthing location from the best position .
c_{2i} = The penalty cost per unit time of vessel i-th

resulting from a delayed departure over the requested due time.
l_i = The length of vessel i-th.
This value includes the requested gap between adjacent vessels.
z^x_{ij} = 1: if vessel i-th is located in the left-hand side of vessel j-th 0: otherwise.
z^y_{ij} = 1: if vessel i-th is located lower side of vessel j-th 0: otherwise.
The objective function of the berth-planning problem can be written as follows:

$$\min \sum_{i=1}^{N} \left\{ c_{1i} \left| x_i \sum p_i \right| + c_{2i} \left(y_i \sum b_i \sum d_i \right)^+ \right\} \quad (1)$$

where:

$$x^+ = \max\{0, x\} \quad (2)$$

The first term of the objective function comes from the deviation of the berthing position from the best location and the second term is related to the penalty cost from the delay of the departure of vessels behind the requested departure time.
The model for the Berth Planning can be expressed in figure 1 where two different ships (i-th and j-th) are presented according to the above-mentioned notation.

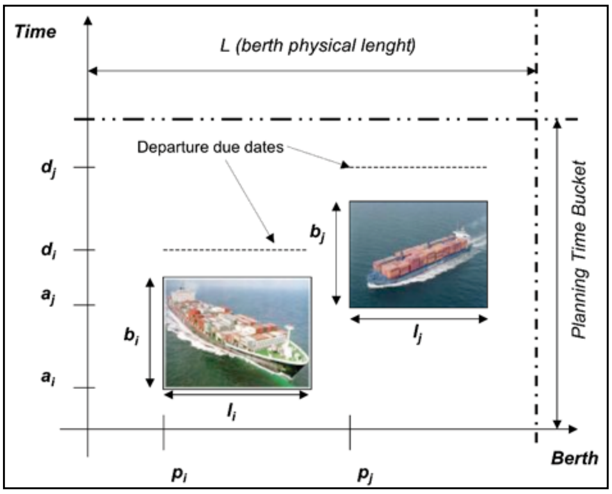

Figure 1: Model for Berth Planning

In order to implement the planning model some transformations in the variables and in the Objective Function have to be taken, in particular 4 new variables have to be defined as follows:

$$\geq_i^+ = \left| x_i \geq p_i \right| : x_i \geq p_i \geq 0 \quad (3)$$

$$\geq_i^{\geq} = \left| x_i \geq p_i \right| : x_i \geq p_i \geq 0 \quad (4)$$

$$_i^+ = \left(y_i + b_i \quad d_i \right) : y_i + b_i \quad d_i \quad 0 \quad (5)$$

$$_i = \left(y_i + b_i \quad d_i \right) : y_i + b_i \quad d_i \quad 0 \quad (6)$$

Following this notation the Objective Function can be defined as follows:

$$\min \sum_{i=1}^{N} \left\{ c_{1i} \left({}_i^+ + {}_i \right) + c_{2i} {}_i^+ \right\} \quad (7)$$

subject to the following constraints:

$$x_i \# p_i = \#_i^+ \# \#_i^\# \# i \quad (8)$$

$$y_i + b_i \# d_i = \#_i^+ \# \#_i^\# \# i \quad (9)$$

Other constraints must be added in order to guarantee that the position of the rightmost end of vessel i will be restricted by the length of the berth (10) and to ensure that two adjacent vessels will never be in conflict with each other with respect to the berthing time (11) and the berthing position (12). In these last constraints M is a big (i.e. 100000) value that void the relationship when the respective z_{ij} is different from 1. Constraint (13) excludes the case in which case the rectangles representing schedules for vessel i and j overlap with each other. Constraint (14) implies that a vessel cannot berth before she arrives.

$$x_i + l_i \; \forall L : \forall i \quad (10)$$

$$y_i + b_i = y_i + M\left(1 \quad z_{ij}^y\right) : \quad i \quad j : i \quad j \quad (11)$$

$$x_i + l_i = x_i + M\left(1 \neq z_{ij}^x\right) : \neq i \neq j : i \neq j \quad (12)$$

$$z_{ij}^x + z_{ji}^x + z_{ij}^y + z_{ji}^y : \neq i \neq j : i \neq j \quad (13)$$

$$y_i \; \forall a_i : \forall i \quad (14)$$

To this constraint is necessary to add the common non negative ones and the integer constrains on the binary variables z_{ij}.

$$\forall_i^+, \forall_i^\forall, \forall_i^+, \forall_i^\forall, x_i \; \forall 0 : \forall i \quad (15)$$

$$z_{ij}^x, z_{ij}^y \left\{ \begin{matrix} 0 \\ 1 \end{matrix} \right. : \neq i \neq j : i \neq j \quad (16)$$

Since the problem is known to be NP-hard practical solutions can be obtained only within 7 arriving ships and 72 hours of planning time buckets that is suitable for on-line, real time planning where the uncertainness of the arriving forecast is still reasonable.
For problems exceeding this sizes several heuristics are available in literature.
The proposed methodology is now based on the integration among arriving forecast process (time series analysis and regression), berth planning and yard planning. This last point is generally managed by using a simulator to support the choice of the container best location. According to the nature of the goods transported the entire container yard is divided in various areas and, inside of this area into various physical locations. Since each container can be part of a stack a handling coefficient has to be considered for each area and each location: HC_{ahk}.(t) Handling Cost coefficient is generally calculated as squared value of the stack size within the upper limit of the stack itself. In this way container from a cargo presents a base handling cost given by (17), where a is the area, t is the time, h is the row position, k is the colum position on the container yard and g_{shk} has the value of 1 for each container from a cargo placed, in the yard, in position

h-th k-th from s-th ship.

$$BHC_s(t) = \sum_{a=1}^{Areas}\sum_{h=1}^{Row}\sum_{k=1}^{Cols}\left(HC_{ahk}(t) \cdot g_{shk}\right) \qquad (17)$$

Since the terminal situation is continuously changing the base handling cost for c-th cargo and s-th ship is changing according to the time. Total cost supported by the terminal C for managing containers that belong to the time bucket can be calculated as follow where the loading/unloading instant can be calculated for each i-th ship as time y_i:

$$C = \sum_{i=1}^{N}\left\{\begin{array}{l} c_{1i}\left|x_i - p_i\right| + c_{2i}\left(y_i - b_i - d_i\right)^{+} \\ + \sum_{a=1}^{Areas}\sum_{h=1}^{Row}\sum_{k=1}^{Cols}\left[HC_{ahk}(y_i) \cdot g_{ihk}\right] \end{array}\right\} \qquad (18)$$

The simulator is, then, used to better estimate the second term of (19) where the time depended situation of the yard is varying within the simulation.

The Linear Programming model was implemented using LINGO™ and embedded into a Java based simulator that models the container yard management.

Data were efficiently stored in an ODBC RDBMS and successfully connected to the embedded LINGO™ solver. Thanks to the possibility of defining generally a Linear Programming problem into the embedded solver. The authors successfully implemented a tool able to assist managers in every day terminal operations.

Recent development have pointed up the opportunity of integrate a railroad simulator model that is under implementation in the CIELI Laboratory in order to support the input/output operations of the containers arriving and leaving the terminal from land.

CONCLUSIONS

Modeling and simulation in the field of maritime container logistics operations has proven to be an effective technique able to solve complex problems and support managers in taking their decision.

Combination of both mathematical modelling and discrete event simulation can be regarded as a powerful approach for increase the robustness of the decision making process by evaluating different scenarios.

The proposed implementation combined all the presented techniques into software tools continuously updated from harbour ERP effectively serving as terminal DSS.

A real life application in the La Spezai terminal has now finishing its implementation phase and is actively demonstrates the benefits of the proposed methodology.

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