THE ROLE OF SIMULATION AND OPTIMISATION IN INTERMODAL CONTAINER TERMINALS

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ABSTRACT

A review of how simulation and optimisation techniques have been applied to help and improve the management of intermodal container terminals is presented. The paper does not provide a detailed list of references and of existing software packages, since it would be very hard for such a list to be complete and exhaustive. This paper aims to identify the major problem classes whose instances can be found in the operations of container terminals, then to discover which approaches have been chosen to solve these problems and, finally, understand why a given solution has proven successful and why some problem classes have not deserved the same attention obtained by some other classes. On the basis of this review, some research directions are proposed towards the application of simulation and optimisation tools and techniques to the problem of container terminal management.

INTRODUCTION

Intermodal terminals are the hubs through which most of world cargo is routed through. Intermodal transport can be viable not only for trans-oceanic shipping, but also for intra-continental transport competing with road-only based shipping. The advantages, in a traffic-congested Europe, are not only economical, but also environmental. For this reason, improving the efficiency and throughput of intermodal terminal is a key factor for success. For the Operations Research practitioner an intermodal terminal is a land of opportunities, as shown in Psaraftis (1998) where the author outlines his approach as an academic to the new role of General Manager of the Piraeus Port Authority. In the paper he highlights the following OR/MS type problems he identifies: scheduling berthing priorities; berth booking by "rendezvous"; allocation of ships to berths and cranes; yard management; route and schedule consolidation of ships. This is evidently not an exhaustive list, we can think of the problem of finding the best ship loading and unloading sequence (Mastrolilli, 2000), but Psaraftis' list is exemplary since it demonstrates the OR/MS approach to a big and complex problem: hierarchical decomposition in simpler problems.

In the following, first we introduce the guideline we have adopted in our approach to the problem of intermodal terminal management, the division of the problem according to the time scale. We then show how available data must drive the modelling process and we explain how the solutions to the different sub-problems (in our example, yard management, resource allocation, ship-loading and unloading) must be integrated to achieve an improvement in the terminal performance. Finally, we suggest simulation as the assessment tool to validate the problem solutions.

DIVIDING MANAGEMENT TASKS ALONG THE TIME SCALE

A distinctive feature of the problem of managing container terminals is the great difference in the length of the planning horizons: planning the destination of use of yard areas is done on a time scale of weeks, while berth planning, and resource allocation are performed only a few days in advance. Stowage plans are prepared a few hours before the ship arrives, while, finally, loading and unloading list are prepared both a few minutes the operations start and often in real-time, taking decisions according to the situation at hand.

It is evident that it is not possible to formulate all these sub-problems as a single comprehensive problem, not only for the complexity of it, but also for the different dynamics of the sub-problems. Basic control theory comes to help, suggesting the separation of the systems with a "slow" dynamic from the ones with a "fast" dynamic. Thus, the problems, formulated over different planning horizons, can be safely separated and solved independently. Such an approach has been presented in (Gambardella *et al.* 1999). On the basis of these observations, we aim at classifying simulation and optimisation techniques according to the space and time domain they target.

Problem decomposition can be a successful solution strategy only when coupled with the use of very fast and efficient algorithms, since only by means of iterated "what-if" analyses it is possible to understand how variations in the "slow-dynamics" systems affect the solutions of the "fast" systems. We will also try to understand how much effort have the authors of the algorithm put into refining their products, since we reckon speed is a necessary condition in the solution of these problems.

THE ROLE OF EDP AND EDI INFRASTRUCTURES

It is trivial to remark that terminal management problems can be studied and eventually solved only when data is available. It is also straightforward to observe that data collection must follow problem formulation. In other words, first we must decide which management problems we want to solve, then we must carefully design a data collection campaign. Despite this, often the management must face the cost and time associated with dedicated data collection and must rely data sets that are already available, to save time and resources.

A favourable opportunity is provided by the fact that Container terminals always collect a good deal of data for customs and accounting reasons. Unfortunately, for the main part, these data are related to the monitoring "input/output" operations, i.e., when a container enters and leaves the terminal and, consequently, these data are not well suited to support the study of the internal terminal processes. Then, at the beginning of the 1990's, some important terminals, notably the port of Antwerp and the port of Singapore, started to collect data to use them for planning and automation of terminal operations, giving birth to a new generation of EDP tools: the so-called "Port and terminal Operating Systems".

These tools required the introduction of advanced data collection techniques, for instance, in the port of Rotterdam containers are tagged by a radio-transmitting device, which allows monitoring all the container moves during its stay in the terminal. Some of these systems are integrated with Geographical Information Systems and they can provide a wealth of data for which the system analysts are always hungry. Nevertheless, these systems are very costly to set-up and even maintain, and only the major terminals are able to afford them. Smaller terminals still rely on manual data entry. Moreover, most terminals store their data on legacy information systems, minicomputers or even mainframes, which were originally chosen on the basis of the accounting system they had to run, not for providing data to manage port operations.

Data availability is therefore a major issue in planning the application of simulation and optimisation techniques to port management. Often, the analyst must convert or reconstruct data from existing databases and this can be a task as demanding as solving the problem itself.

To overcome these problems Port Authorities are working towards the implementation of port-wide information systems. An example is represented by the project of the Rotterdam Port CommunITy* where they have implemented the EDI-LAND project for the electronic data interchange along the complete container logistic chain and "Cargo Card" project, where a smart card gives each driver his own 'electronic identity'. The data stored in this card are exchanged among the different parts of the port system: the terminal operators, the shipping companies, the forwarders, etc.

The bottom line is that *EDI and EDP infrastructures are a pre-requisite for simulation and optimisation of terminal operations*

TRENDS IN OPTIMISATION AND SIMULATION IN INTERMODAL TERMINALS

Terminals tend to develop a strong appetite for operations planning based on data analysis and interpretation once they have installed an efficient EDI/EDP system. Research institutes and consulting companies have understood these needs for a long time, and often these companies were spin-offs of the research divisions of the terminal operators themselves.

The provided solutions span a broad spectrum, from the very focused study, custom-made for the singe terminal, to the general "Port Operating System", designed to be integrated with the most common EDI systems and to be applied in the most varied situations.

Not only are the solutions different, but also the people working at them. Universities and research institutes tend to bring in their expertise in solving academic problems and apply it to the real world case studies. The main focus is to demonstrate that innovative optimisation algorithms can be applied in real world situations. Often the proposed solution is not transferred to operational management, since this would require lots of menial tasks to be performed, such as writing code to integrate the algorithm into the terminal EDP system. This is not a priority for academic research, so these studies only rarely find their way into the port management practices.

On the other end of the spectrum we find terminal operators themselves that, under the pressure of customer demand and container traffic, need to optimise their performance, taking better management decisions. This approach has given birth to many spin-off companies that have proven quite successful in designing software tools that can be used for port management. Among these we find Cosmos NV (http://www.cosmos.be), Navis LLC (http://www.navis.com), the Port of Singapore itself (http://www.psa.com.sg/), and many others. Most of these tools aim at providing decision support for the terminal operators, concentrating their efforts in creating a seamless interface with the EDP systems and in the graphical interaction with the user.

THE NEED FOR INTEGRATED TERMINAL MANAGEMENT

Why the system analysts have mostly focused their attention on ship stability and stowage planning problems while neglecting what is happening on the yard? A possible answer to this question is found looking at the background of a number of terminal managers. They are former ship captains and they are led to see the ship as the central point of the operations, while the yard is there to serve the ship. Moreover, they are basically "risk-averse", and do not want to incur in the expensive penalties the terminal has to pay to the shipping company when the ship deadline is trespassed. This has led to a demand for algorithms and software tools to help ship-centred operations, while leaving the yard operations at the margins. Only recently both research organisations and terminal operators have started to investigate in the direction of a deeper interaction in the management of yard and ship operations (Bruzzone and Signorile, 1998).

On the basis of the experience we have matured working both port and in-land terminals (Gambardella

* See the web page: http://www.pcr-info.nl/e/index.htm

et al., 1998; Mastrolilli *et al.* 1998; Zaffalon *et al.*, 1998; Rizzoli *et al.*, 2000), we believe that to improve terminal management the operators must consider all the different aspects of the container flows at different time scales, finding the appropriate modelling assumptions to separate the comprehensive problem in smaller, more manageable, sub-problems.

According to this view, the terminal operators must use historical data to produce reliable forecasts of container flows, according to the ship schedules and the terminal characteristics. The forecasting algorithms need to be re-calibrated only when the ship schedules pattern change, i.e., with a time horizon in the range of few months.

These forecasted flows can be used as inputs to produce medium term yard space allocation policies (Kim and Kim, 1999a). These policies depend on the ship types and their previous and next port-of-call. The pattern of ship arrivals is also known a few weeks in advance, so the planning horizon can be in the order of few weeks.

The ship loading and unloading lists, that is, the list of containers to be moved by a ship, is known a few days before the ship arrivals. This information, together with the information on the container destinations on yard, makes possible the planning of resources allocations.

Finally, an even shorter planning horizon, in the order of hours, is used to compute the loading and unloading plans, optimising the crane moves both on yard and on ship, on the basis of the allocated resources.

Making *yard and ship resources work co-operatively*, yard conflicts can be reduced and the overall terminal performance can be increased, as shown by Mastrolilli et al (1998).

It is especially at this planning level, focused on few hours, that most of acdaemic research has focused its attention (see for instance Kozan and Preston, 1999; Chen *et al.*, 1995; Kim and Kim, 1999b).

SIMULATION FOR PORT OPERATIONS

The role of simulation to evaluate alternative management policies is fundamental, especially when the policies are computer generated and the human decision-makers have not a complete understanding of all their details. Moreover, computer generated policies are obtained from modelling assumptions that can often seem too restrictive in comparison to the complexity and the stochasticity of real world operations. A well-designed simulation tool can be the middle ground where the decision-makers compare their own experience with the DSS generated management policies and validate them.

Calibration and validation play a very important role since the terminal operators must actively co-operate with the simulation specialists in order to gain confidence in the model results (Balci, 1998). Advanced graphical interfaces and virtual reality can also be useful to provide immediate insight into the model workings even to the operators with scarce technical background (Nevins *et al.*, 1998).

Both the producers of Port Operating Systems and the academic researchers have often overlooked simulation. The formers have focused their attention on the presentation of the available data to the terminal managers, concentrating on traditional statistical techniques, rather than simulation, for scenario “what-if” analyses. The academic researchers, on the other hand, have often found the application of innovative Operations Research algorithms to real world case studies more rewarding than the nitty-gritty implementation of a detailed simulation system.

Nevertheless, there are some studies that show the usefulness of simulation in the management of a terminal. The work of Hayuth *et al.* (1995) summarizes the efforts made by various modellers and aims at the creation of a versatile tool for the simulation of berth operations in a port. A recent EU-funded project (Blümel *et al.* 1997) has shifted the attention to the simulation of the whole terminal, as composed by yard and quays. Finally, our research group has developed two simulation systems, the first focused on the evaluation of terminal management policies in a port (see Gambardella *et al.*, 1998), the second directed at the simulation of intermodal rail-road terminals as hubs in an inland transportation network (Rizzoli *et al.*, 2000).

CONCLUSIONS

We have examined the impact of simulation and optimisation in the management of intermodal container terminals. First, we remarked how a successful approach must be based on the temporal decomposition of the global management problem into smaller problems. Second, we highlighted the importance of EDP and EDI infrastructures and briefly introduced the most notable instances in some important ports.

Third, we noted how the terminal yard and the quays must be managed in an integrated fashion, that is, taking into appropriate account the different processes which take place simultaneously in these two focal parts of the terminal.

Finally, we presented simulation as an important tool for both the evaluation of "what-if" scenarios and the assessment of terminal management policies.

REFERENCES

Balci, O. 1998. "Verification, validation, and testing." In: *Handbook of Simulation*, J. Banks ed. John Wiley & Sons, New York, 335-393.

Blümel, E., Ginters, E., Merkuryev, Y., et al. 1997. Managing and Controlling Growing Harbour Terminals, Ghent: SCS Europe BVBA.

Bruzzone, A., Signorile, R. 1998. "Simulation and genetic algorithms for ship planning and shipyard layout." *Simulation* 71, No 2: 74-83.

Chen, C.S., Lee, S.M., Shen, Q.S. 1995. "An analytical model for the container loading problem." *European Journal of Operational Research* 80, no. 1: 68-76.

Gambardella L.M., Rizzoli A., Zaffalon M. 1998. "Simulation and planning for intermodal container terminal." *Simulation* 71, No 2: 107-116.

Hayuth, Y., Pollatschek, M.A., Roll, Y. 1994. "Building a port simulator." Simulation 63, no. 3: 179-189.

Kim, K.H., Kim, H.B. 1999a. "Segregating space allocation models for container inventories in port container terminals." *International Journal of Production Economics* 59, Nos. 1-3: 415-423.

Kim, K.H., Kim, K.Y., 1999b. "Routing straddle carriers for the loading operation of containers using a beam search algorithm." *Computers & Industrial Engineering* 36, No. 1: 109-136.

Kozan, E., Preston, P. 1999. "Genetic algorithms to schedule container transfers at multimodal terminals." *International Transactions in Operational Research* 6, No. 3: 311-329.

Mastrolilli, M., Fornara, N., Gambardella, L.M., Rizzoli, A.E., Zaffalon, M. 1998. "Simulation for policy evaluation, planning and decision support in an intermodal container terminal." In: Proceedings of the International Workshop "Modeling and Simulation within a Maritime Environment", Y. Merkuryev, A. Bruzzone, L. Novitsky, eds. Society for Computer Simulation International, 33-38.

Mastrolilli, M., Gambardella, L.M. 2000. "Effective neighborhood functions for the flexible job-shop problem." *Journal of Scheduling* 3: 3-20.

Nevins, M.R., Macal, C.M., Love, R.J., Bragen, M.J. 1998. "Simulation, animation and visualization of seaport operations." *Simulation* 71, No 2: 96-106.

Psaraftis, H.N. 1998. "When a port calls …an operations researcher answers." *ORMS Today*, April 1998.

Rizzoli, A.E., Fornara, N., Gambardella, L.M. 2000. "A simulation tool for combined rail/road transport in intermodal terminals." Accepted for publication *Mathematical and Computer Modelling*.

Zaffalon M., Rizzoli A.E., Gambardella L.M., Mastrolilli, M. 1998. "Resource allocation and scheduling of operations in an intermodal terminal." In: ESS 98 Simulation in Industry 1998, A. Bargiela and E. Kerchhoffs eds. Society for Computer Simulation International.

BIOGRAPHY

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