Optimization at Container Terminals: Status, Trends and Perspectives

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May 28, 2008

Report TRANSP-OR 080528
Transport and Mobility Laboratory
Ecole Polytechnique Fédérale de Lausanne
transp-or.epfl.ch

Revised version of report TRANSP-OR 071204 by Vacca, Bierlaire, Salani.

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Abstract

International sea-freight container transportation has grown dramatically over the last years and container terminals represent nowadays a key actor in the global shipping network. Terminal managers have to face with an increasing competitiveness among terminals, which require more and more efficiency in container operations both along the quayside and within the yard: the objective is usually to minimize ship's turnaround time, one of the main indicators of the terminal performance for the shipping companies. Moreover, the minimization of operational costs directly entails the achievement of competitive terminal fares, thus increasing the attractiveness for new customers. Operations research methods and techniques are therefore worth being used in optimizing terminal operations. In this work, we firstly give an overview of decision problems which arise in the management of a container terminal (e.g. berth allocation, quay crane scheduling, storage policies and strategies, transfer operations, ship stowage planning) and provide a review of recent papers in the OR literature. Then, starting from a collaboration with some of the busiest ports in Europe, we identify some critical issues: in particular, we discuss the impact that gate and transshipment operations have on the yard. We also focus on competition and cooperation issues among port market players and decision makers. Finally, we conclude by suggesting possible research tracks and open issues.

1 Introduction

Containerized sea-freight transportation has grown dramatically over the last two decades, about 7-9% per year, while other sea transportation modes have grown around 2% per year (Crainic and Kim, 2007). This trend confirms that the multi-modality feature of container transport is an important factor, among others, that contributes to its growth (any container has a standardized load unit that is suitable also for truck and train transportation). In this framework, container terminals are crucial connections between modes: a bottleneck in terminal operations may affect both inbound and outbound traffic.

In the following table we report the volume of container traffic in TEUs (Twenty feet Equivalent Unit) of the three most busy container terminals in the World and in Europe over the three last years.

Worldwide	2004	2005	2006
1 Singapore	21,329,100	23,190,000 (+8,7%)	24,800,000 (+6,9%)
2 Hong Kong	21,930,000	22,602,000 (+3.0%)	23,230,000 (+2,7%)
3 Shanghai	14,550,000	18,084,000 (+24.3%)	21,700,000 (+20.0%)
Europe	2004	2005	2006
1 Rotterdam	8,291,000	9,287,000 (+12.0%)	9,690,000 (+4.3%)
2 Hamburg	7,004,000	8,087,550 (+15.4%)	8,861,804 (+9.5%)
3 Antwerp	6,062,746	6,482,030 (+6.9%)	7,018,799 (+8,3%)

Table 1: Busiest ports in the World and Europe

A container terminal is a zone of the port where sea-freight dock on a berth and containers are loaded, unloaded and stored in a buffer area called yard. A terminal can therefore be ideally divided into two areas, the quayside and the yard. The quayside is made up of berths for vessels and quay cranes (QC) which move containers. The yard serves as a buffer for loading, unloading and transshipping containers and it is typically divided into blocks: each container block is served by one or more yard cranes (YC), which can be rubber tyred or rail mounted (RTG/RMG), and straddle carriers (SC). The equipment used to operate the yard makes the difference between an intensive and extensive yard utilization: while in intensive yard terminals containers are stored up to 6-7 levels high with a gap of 40cm between rows, in extensive yard terminals stacks are limited to 3 or 4 levels high with a gap of 150cm between rows. Finally, to transport containers between quayside and yard, between yard and gates and to relocate containers within the yard, straddle carriers, automatic guided vehicles (AGV) or internal trucks are commonly used. Recently, container transport tends to develop toward a particular case of single-mode transportation, which is called *transshipment*, where containers are exchanged between ships commonly referred as *mother vessels* and *feeders*. In transshipment hubs, many of the multi-modality issues of import/export terminals are concentrated along the quayside: in particular, congestion issues raise when mother vessels and feeders are performing simultaneously loading and unloading operations.

Container terminals are not only simple connections between transportation modes; they also represent the site where several market players, who act around maritime transportation, trade for their business. With respect to the viewpoint of a terminal authority, we are able to identify several market players (Henesey, 2006):

- The internal stakeholders are part of the terminal authority organization and usually pursue different objectives. We identify commercial, operational and security departments.
- The external stakeholders are market players linked to the terminal by economic or contractual relationships. We identify port companies and supporting industries that invest directly in the port area and industries located in the surroundings of the port who make their business in relation with a port company (mainly involved in physical transport operations).
- Terminal customers such as importers/exporters. They normally do not invest directly in the terminal but they have strong indirect decision power, since they can require particular standards of service. Nevertheless, they are strictly correlated with terminal evolution, because port activity can influence their business results.
- Legislation and public policy: government departments responsible for transport, economic affairs, environmental departments and spatial planning authorities.
- Union of workers: they trade with the terminal managers some of the constraints linked to the manpower employed to operate the terminal.
- Community: civil society organizations and the press.

Terminal managers should take into primary consideration the interests of actors who are most critically involved in a context where objectives are conflicting. Interesting studies concerning competition and cooperation among players in container transportation have been presented by Heaver et al. (2000), Heaver et al. (2001) and Vanelslander (2005).

The themes of competition and competitiveness are nowadays very relevant indeed. Besides competing with terminals in other ports, terminal managers are faced against competition issues even among terminals of the same port. The biggest ports in the world often consist of several terminals: the port of Hong Kong consists of 9 container terminals operated by 5 companies; the port of Rotterdam has 13 container terminals; the port of Hamburg has 4 dedicated container terminals and 8 multi-purpose terminals able to handle containers, just to mention a few examples. Competitiveness is therefore a crucial issue to survive in the market, given that a shipping company which decides to serve a certain port with regular services has also the possibility to choose the most appropriate terminal for its business.

In this context, new objectives and performance measures need to be identified and employed to evaluate the performance of a container terminal. Clearly defined KPIs (Key Performance Indicators) allow to adopt decision support systems that optimize objective functions based on such indicators. We can distinguish two main classes of KPIs:

- *service-oriented*: they measure the service levels provided to clients and are usually expressed by the turn-around time of both ship liners and outside trucks. This class of indicators needs to be developed in order to take into account competitiveness. It includes berth service time (i.e. vessel turn-around time in hours, vessels time to berth, vessels berthed on time, etc.) and gate service time (i.e. truck turn-around time at the gates, trucks still on terminal over 1 hour, etc.);

- *productivity-oriented*: they measure the volume of containers' traffic managed by the terminal in relation to the available resources; common indicators are TEU volume growth (TEUs per year), crane utilization (TEUs per year, per crane), crane productivity (moves per crane, per hour), berth utilization (vessels per year, per berth), land utilization (TEUs per year, per gross acre), storage productivity (TEUs per storage acre) and gate throughput (containers per hour, per lane).

For more details on performance indicators we refer the reader to Meersman et al. (2004) and Le-Griffin and Murphy (2006).

Terminal authority managers have the possibility to optimize the above-mentioned objectives at several stages, called planning levels. We can distinguish three planning levels:

- the *strategic level* is related to the terminal design and involves long-term decisions regarding terminal layout, terminal equipment, berth and yard capacity, strategic alliances with shipping companies and multi-modal interfaces;

- the *tactical level* is related to mid-term and short-term planning and involves decisions regarding berth and yard templates and storage policies;

- the *operational level* is related to operative planning and real-time control and involves decisions regarding quayside operations (berth allocation, quay cranes scheduling, ship stowage), landside operations (transfer operations, yard management) as well as the management of empty containers and human resources.

In this paper, we review the most recent contributions in the operations research (OR) literature concerning the optimization of container terminal operations and we identify recent trends. We present two case studies and we outline the similarities among problems we identified in the terminals of Antwerp (Belgium) and Gioia Tauro (Italy), which are different in nature: Antwerp is mainly an import terminal, while Gioia Tauro is a transshipment one. Finally, we use our understandings of the literature and of the two real situations to present some research directions which, in our opinion, are worth investigating.

2 Literature Review

Container terminal operations have received increasing interest in the scientific OR literature over the last years. For a general overview of container terminals and a survey of optimization models and methods for their operations, we mainly refer to Vis and de Koster (2003) and Steenken et al. (2004). Vis and de Koster (2003) illustrate the main logistics processes which take place in container terminals (arrival of the ship, loading and unloading operations, transfer and stacking of containers) and provide a review of relevant literature (about 50 references up to 2001). Steenken et al. (2004) provide an exhaustive overview of methods for the optimization of container terminal operations (about 200 references up to 2004), in addition to a detailed description of the terminal structure and handling equipment. Additional references concerning container terminal operations are Kim (2005), Murty et al. (2005), Günther and Kim (2005).

In the remainder of this section we provide a review of recent papers (from 2004) which illustrate and solve typical decision problems arising in the management of container terminals. A similar survey (Stahlbock and Voss, 2007) has been just published online by the same group of authors of (Steenken et al., 2004), who provide an update with respect to their 2004 review. Whereas Stahlbock and Voss provide a very comprehensive survey of the literature, in our work we aim not only to present recent papers, but also to identify new trends and directions in the scientific research which can be meaningful in real world application (the case studies illustrated in Section 4 give us a better understanding of real issues in container terminals).

Berth Allocation The Berth Allocation Problem (BAP) refers to the problem of allocating ships to berths (discrete case) or to quays locations (continuous case). Constraints and issues are ship's length, berth's depth, time windows and priorities assigned to the ships, favorite berthing areas, etc.

Imai et al. (2005) address the continuous BAP with the purpose of minimizing the total service time of ships, when handling time of a ship depends on the quay location assigned to it. They present a heuristic algorithm which solves the problem in two stages, by improving the solution for the discrete case. Tests are performed on generated instances with quay-length up to 1600m and up to 60 ships to be allocated.

Cordeau et al. (2005) consider both the discrete and the continuous BAP. Two formulations and two tabu search heuristics are presented and tested on realistic generated instances (up to 35 ships and 10 berths), derived by a statistical analysis of traffic and berth allocation data of the port of Gioia Tauro (Italy). The terminal managers plan to incorporate the heuristics in its decision support system.

Moorthy and Teo (2006) address the design of a berth template, a tactical planning problem which arises in transshipment hubs and which concerns the allocation of favorite berthing locations (home berths) to vessels which periodically call at the terminal. The problem is modeled as a bicriteria optimization problem, which reflects the trade-off between service levels and costs. The authors propose two procedures able to build good and robust templates, which are evaluated by simulating their performances; robust templates are also compared with optimal templates on real-life generated instances.

Imai, Nishimura, Hattori and Papadimitriou (2007) consider the case of indented berths, where multiple small ships can be served by the same berth simultaneously. The problem is formulated as an integer linear problem and solved by genetic algorithms. Solutions are evaluated by comparing the indented terminal with a conventional terminal of the same size: tests on generated instances show that the total service time for all ships is longer in indented terminals, although mega-ships are served faster.

Wang and Lim (2007) propose a stochastic beam search scheme for the BAP. The implemented algorithm is tested on real-life data from the Singapore Port Terminal (the size of instances is up to 400 vessels); it outperforms state-of-the-art metaheuristics, providing better solutions in shorter running times.

Monaco and Sammarra (2007) propose a strong formulation for the discrete BAP as a dynamic scheduling problem on unrelated parallel machines and develop an efficient Lagrangean heuristic algorithm. Instances up to 30 ships and 7 berthing points are solved reaching near-optimal solutions in short computational time.

Quay Crane Scheduling The Quay Crane Scheduling Problem (QCSP) refers to the allocation of a fixed number of quay cranes to tasks (i.e. sets of containers) as well as to the scheduling of loading and unloading moves. Issues related to interference among cranes, precedence and operational constraints must be taken into account.

Lim et al. (2004) address the problem of assigning cranes to tasks under non-crossing, neighborhood and separation constraints. The authors propose dynamic programming algorithms, a probabilistic tabu search and a squeaky wheel optimization heuristic for the solution; the algorithms are tested on generated instances which reflect the actual situation in the Port of Singapore (their size is up to 30 cranes and 40 tasks).

Kim and Park (2004) address the problem of finding the optimal sequence of loading and unloading operations of a quay crane which minimizes the completion time. A branch-and-bound algorithm is proposed as well as a greedy randomized adaptive search procedure (GRASP): both solutions are tested on generated instances involving up to 6 cranes and 50 tasks.

Moccia et al. (2006) propose a new formulation for the QCSP and solve the problem using a branch-and-cut algorithm. Tests are conducted on the generated instances introduced by Kim and Park (2004) and the two algorithms are compared: branch-and-cut outperforms branch-and-bound on medium-size instances and is proved to be able to handle realistic-size instances.

Sammarra et al. (2007) decompose QCSP into a routing and a scheduling problem and propose a tabu search algorithm for the routing problem, which is embedded into a local search procedure for the scheduling problem. Results are compared to the GRASP of Kim and Park (2004) and to the branch-and-cut of Moccia et al. (2006). The propose algorithm outperforms GRASP and is able to find the optimum on several instance in a reasonable computation time.

Yard Operations The management of yard operations involves several decision problems: the design of storage policies at the block and bay level according to the specific features of the container (size, weight, destination, import/export etc.); the allocation, routing and scheduling of yard cranes; the design of re-marshalling policies for export containers.

Ng and Mak (2005) propose an exact solution to the scheduling of different jobs assigned to a yard crane, in order to minimize the sum of job waiting times. The authors propose a new formulation and some bounds, which are used to design a branch-and-bound algorithm. Tests executed on generated instances, based on real data collected from Singapore and Hong Kong, show that the algorithm performs well for most of the instances.

Ng (2005) also addresses the same scheduling problem with additional constraints due to the interference among yard cranes. A formulation is presented and solved using a dynamic programming-based heuristic. The algorithm is tested on randomly generated instances based on realistic data and results are confronted with a lower bound devised by the author.

Kang et al. (2006) study stacking strategies for export containers when weight information is not available. The strategy, determined by a simulated annealing algorithm, is confronted with other traditional stacking strategies by means of simulation: results show that the number of container re-handlings is significantly reduced. Accuracy can be further improved by applying machine learning techniques.

Lee et al. (2006) address a yard storage allocation problem in a transshipment hub with the objective of reducing reshuffling and traffic congestion. They aim to assign containers to sub-block locations as well as yard cranes to blocks and propose a mixed integer linear programming model which minimizes the number of cranes needed to handle the total workload. Two heuristics are proposed and tested on generated instances: a sequential method and a column generation algorithm.

Lee and Hsu (2007) present a model for the container re-marshalling problem: in order to utilize yard space more efficiently and speed up loading operations, they propose to re-marshal containers in such a way that they fit the loading sequence. The problem is modeled as a multicommodity flow with side constraints: the model is able to re-position export containers within the yard, so that no extra re-handles will be needed during the loading operations. A solution heuristic is discussed and computational results over synthetic instances close to real ones are provided.

Cordeau et al. (2007) present the service allocation problem, which is a yard-related decision problem arising in the transshipment terminal of Gioia Tauro (Italy). This problem occurs at the tactical planning level; the objective is to minimize the housekeeping operations i.e. the handling operations within the yard. The authors propose a quadratic mathematical model to the problem and two linearizations; they propose a memetic algorithm to solve instances derived from real world situations and they compare their solution against a commercial MIP solver.

Transfer Operations Containers are usually transferred from the quay-side to the yard, from the yard to the gate and viceversa by internal trucks, straddle carriers and AGVs. The objective in optimizing transfer operations is usually to minimize the vehicle fleet size.

Liu et al. (2004) present some simulation models developed to evaluate the impact of two commonly-used yard layouts on the terminal efficiency when AGVs are used. The performance in both cases is assessed using a multi-attribute decision making method: results show that yard layout affects the size of the equipment fleet as well as the performance of the terminal. Real data provided from Norfolk International Terminal (USA) are used to validate the models.

Vis et al. (2005) propose to use buffer areas in the transfer quay-yard, so that the process can be decoupled in two subprocesses: unloading and transportation. An integer programming model determines the minimum size of the fleet such that each container is transported within its time window. Analytical results are validated by simulation: numerical experiments show that the model provides a good estimate of the number of vehicles needed.

Cheng et al. (2005) study the problem of dispatching AGVs by taking into account the effect of congestion. A network flow model is presented and used to determine the appropriate number of vehicles to deploy; the objective is to minimize the waiting time of AGVs at the berth. Simulation results show that the proposed method increases the throughput of the terminal.

Lee et al. (2007) present a model to solve the scheduling of two-transtainer systems: one quay crane is served by two transtainers which retrieve containers from two different yard areas. The objective is to minimize the total loading time. The model is solved by simulated annealing.

Ship Stowage Planning The stowage of a containership is a highly constrained problem in which terminal managers don't have the total decisional power: loading plans must be formulated accordingly to a given template and validated by the captain of the vessel.

Ambrosino et al. (2006) propose a model for the the Master Bay Plan Problem (MBPP) where the main goal is the minimization of the loading time of all containers, given that all other ship movements have a fixed and known duration. The authors propose a three phase algorithm based on a partitioning procedure of the ship, an assignment phase of containers to ship portions and an heuristic algorithm. They also propose methods to check and validate the ship stability of the overall stowage plan.

Imai et al. (2006) present a multi-criteria optimization method to the ship stowage problem which takes into account two contrasting objectives: the ship stability and the number of container re-handles. The authors propose a multi-objective integer programming model and they implement a weighting method to come up to a single objective function. Computational experiments for instances with up to 504 containers are provided.

Sciomachen and Tanfani (2007) formulate the MBPP as a three-dimensional bin packing problem and present a heuristic solution method which is based on this relation. Objectives are to minimize the total loading time as well as to efficiently use the quay equipment. The approach is validated by using real test cases from the port of Genova (Italy).

3 Trends in the OR Literature

Analyzing the recent OR literature concerning container terminal operations we have identified some trends:

Specialization on a single problem Many of the reviewed contributions are mainly dedicated to sophisticated models for single decision problems at container terminals. Thanks to the expertise acquired form previous work, some authors develop an accurate insight and enrich the details of the models to provide more reliable solutions.

The berth allocation problem is widely investigated by Imai et al. (2003), Imai et al. (2005), Imai et al. (2008) and Imai, Nishimura, Hattori and Papadimitriou (2007) under several aspects (e.g. allocation with or without service priority) and scenarios (e.g. limited quay capacity, indented berths).

Yard operations are exhaustively studied by Kim and Bae (1998), Kim and Kim (1999), Kim and Kim (2002), Kim and Park (2003), Kim and Hong (2006), Kim and Lee (2006), Kang et al. (2006) and Yang and Kim (2006): the group of authors investigate storage and stacking policies for import and export containers as well as re-marshalling strategies.

Combination of problems and integration Within this trend, authors with experience on single optimization problems try to combine the problems and the solution methods into a unique approach.

Park and Kim (2003), Meisel and Bierwirth (2006) and Imai, Chen, Nishimura and Papadimitriou (2007) work on the integration of berth allocation and quay crane assignment.

Bish et al. (2001) and Kozan and Preston (2006) propose the integration of yard block allocation and container transfers.

Goodchild and Daganzo (2006) and Goodchild and Daganzo (2007) consider the double cycling of quay cranes and its impact on loading/unloading operations.

Chen et al. (2007) and Lau and Zhao (2007) study the integrated scheduling of handling equipment in a container terminal.

Simulation and queuing theory, complete terminals The container terminal is here considered as a global system: instead of single optimization problems, the entire flow of containers is considered and optimized.

Gambardella et al. (1998), Maione and Ottomanelli (2005) and Henesey (2006) present the container terminal as a whole system and optimize the flow of containers.

Legato and Mazza (2001) and Canonaco et al. (2007) propose methods for integrated berth planning via simulation.

4 Case studies

In this section, we illustrate two container terminals in the ports of Antwerp (Belgium) and Gioia Tauro (Italy).

Antwerp: an import/export container terminal Antwerp Gateway (`www.antwerpgateway.be`) is a terminal operated by DP World in the port of Antwerp (Belgium). The terminal is currently equipped with 6 ship-to-shore (STS) gantry cranes, 4 automated rail mounted cranes (RMGs), 35 straddle carriers (SCs), 1 RMG for the on-dock rail terminal. Furthermore, 10 additional RMGs will be installed in July 2008 and 3 additional STS cranes will be delivered in 2009. The quay length is 2500m. Its current capacity is 1.4 million TEUs using straddle carriers as operational mode, although the yard stacking equipment is being changed from straddle carriers to automated RMGs: this conversion will allow the terminal to increase its capacity up to 3.5 million TEUs, when the whole terminal will operate in an automatic stacking crane (ASC) mode (up to 96 RMGs will operate in the yard), due to an increase of the yard density. Moreover, RMGs can work by night (performing housekeeping) and one operator in a control station can control several RMGs simultaneously. However, RMGs are in general slower than SCs, because more reshuffling operations occur in higher stacks, and transfer vehicles are still needed to transfer containers from the quayside to the yard. According to the experience of terminal managers, when the yard utilization is more than 75% of the total capacity, the productivity significantly decreases because of reshuffling.

Antwerp Gateway is mainly an import/export terminal with extensive yard utilization; the modal split for container transport is dominated by road transport (60%), followed by inland navigation (30%) and rail transport (10%).

The terminal has control on the gate activities but not on the arrival process of trucks; similarly, it has control on the quay activities but not on the arrival process of barges. Operators do not know in advance which containers are going to be picked-up and when: therefore, without information, optimization is almost impossible.

With respect to the gate, traffic congestion often occurs because trucks usually arrive almost at the same time and without notice. The terminal is therefore trying to implement a so-called Vehicle Booking System (VBS), although truck companies are reluctant to accept it. VBS has been developed by Southampton Container Terminals (UK), also operated by DP World: it enables the haulers to pre-book the container for delivery and/or collection and the terminal to provide better service levels. Peak and off-peak time windows have been defined and a "no show" fee has been introduced. The system, first time in Europe, is in use in Southampton since 2005.

With respect to the quayside, barges and feeders can slow down the operations in the terminal, as they don't have a predetermined schedule (they can arrive at any time in any order). Although they generally represent an efficient transportation mode and a useful alternative to the road transport, they can become a bottleneck for the terminal when the number of containers to be handled per barge is extremely low. In this case, since the duration of berthing operations is much larger than the duration of (un)loading operations (a barge can berth in about 15 minutes), resources such as berths and cranes may stand idle a lot of time.

Gioia Tauro: a transshipment container terminal The Medcenter Container Terminal(`www.portodigioiatauro.it`) is operated by Contship Italia in the port of Gioia Tauro (Italy). The terminal is currently equipped with 18 quay cranes, 80 straddle carriers and has a yard capacity of 61000 TEUs. The quay length is 3,011m. The terminal has already planned developments in order to reach a 3,361m quay length, 22 quay cranes, 3 mobile cranes: the throughput is expected to increase from the current 3.5 million TEUs up to 5.5 million TEUs.

The terminal is a real transshipment terminal (95% of containers are transshipped) with extensive yard utilization; the remaining 5% is mainly transported by trains. The main customer is Maersk, who represents roughly the 65% of the total container traffic; the terminal plans to increase its traffic by 30% thanks to a recent agreement with MSC (about 4 million TEUs are expected in 2007).

The terminal can handle mother vessels up to 350m long carrying 8000 TEUs. Feeders can vary from 200-300 moves for the common feeders up to 1000 for dedicated feeders. Transshipped containers are usually exchanged between a mother vessel and several feeders. Berth planning is performed offline.

Containers may then be stocked far away from the quay side: while the average distance was 350m in 2006, it has increased up to 500m during the first half of 2007. As a consequence, there is an increase of re-handling operations and this fact directly impacts on crane productivity.

Common practices and issues The main costs for the terminal are roughly divided as follows: 50% manpower, 25% fuel and electricity, 25% maintenance costs. Minimizing the total distance covered by containers from quay to yard is therefore an objective which makes sense for the terminal managers, given that fuel and maintenance costs account up to 50% of the overall terminal costs.

As a common practice, feeders and barges are not loaded while the mother vessel is still being unloaded, mainly because containers for the same barge are not always stored close in the ship and it could happen that a barge have to load the first and the last containers unloaded from the mother vessel. Therefore, they prefer to call at the terminal once the mother vessel has been completely unloaded.

The terminal is bound by a contract only with big shipping companies, which usually have periodical services calling at the terminal; consequently, all operations and planning depend on the mother vessel. The objective is to provide what the contract states; in practice, the vessel has to be served as soon as possible (usually there is a contractual minimum moves-per-crane-per-hour). Shipping companies don't require a favorite berth: they are allocated where the terminal decides. Still, for the terminal it's important to have a template: managers try to make this plan and to assign always the same berth and yard zone to a given service, although it's not compulsory and it's not always possible.

5 Perspectives

Thanks to our direct investigation on the field we have identified similarities among the problems of the two above mentioned container terminals. In this section, we illustrate some possible research directions which, in our opinion, are worth of further investigation.

Tactical level Tactical decision problems are not so much present in the literature yet and they definitely need to be studied more in depth. Moreover, we propose to integrate the tactical and the operational planning level and thus define a new class of problems.

This idea is inspired by the papers of Moorthy and Teo (2006) and Cordeau et al. (2007), which address tactical problems arising in transshipment container terminals. Both authors state that, in the real-world practice, the outputs of tactical planning are used as inputs in the operational planning. However, this practice has not been taken into account in the literature: operational problems are often presented in a simplified way, with many assumptions, and their interaction with tactical planning is never mentioned. Only in Cordeau et al. (2005) we find an explicit reference to the berth template: the devised model for the berth allocation takes indeed the berth template as input of the operational problem. We therefore think that it's worth investigating a possible embedding of tactical decisions in the solutions of operational problems.

As a complementary approach, it would be also interesting to take into account operational constraints (in terms of rules, common policies and best practices) in the solution of tactical problems: in this way, the concept of robustness could be eventually introduced in the tactical planning. However, a deep knowledge of operational practices and constraints is required to produce robust solutions.

Market players and decision makers Container terminals represent the connection among market players who trade their business acting around maritime transportation. We think that a better understanding of these relations and of their impact on terminal operations would lead to more meaningful objective functions for optimization tools.

With regard to transshipment, feedering and gate operations, we noticed that they are mainly performed with the only objective of respecting contractual terms with big shipping lines. Both terminals in Antwerp and Gioia Tauro are constrained to a fixed ratio moves/hour. Nonetheless, containers' final destinations (to feeders or gates) are considered only at a second stage. This implies a reshuffling of containers which is of no revenue for the terminal and sometimes difficult to manage (especially when yard utilization is close to maximum capacity).

When this multi-player characteristic is disregarded, two other issues arise: congestion and traffic. To reach their final destination, containers are handled by transporters who optimize their own objective function. They are in competition among each other so they do not share any data and it frequently happens that they show up at the terminal simultaneously because they serve customers with similar characteristics and constraints. This situation generates peaks of service demand both at the quay side (for transshipment terminals) and at the gate side (for import/export terminals) which result in a concentration of loading and unloading operations and in a high utilization of limited shared resources. These issues are even more relevant if we consider that possible disruptions may occur at the terminal (e.g. an equipment failure).

It is clear that a better synchronization among final transporters would have benefits both for them and for the terminal, but we reasonably assume that transporters cannot (or don't want to) coordinate themselves. Since the primal objective for terminals remains the compliance with the service levels promised in the contracts to the big shipping companies, we propose to think of the terminal as a player able to negotiate with final transporters in order to reduce not only the need of reshuffling but also traffic and congestion.

It would be interesting to explore the game theory and pricing policy fields. Some work in this direction has been recently done: Henesey (2006) uses a multi-agent simulation approach for the management of a container terminal; Douma et al. (2007) and Konings (2007) propose techniques to improve the container barge handling in the port of Rotterdam, where several barges daily call at almost all the 13 terminals of the port.

The impact of vehicle appointment systems on gate operations is also worth of investigation. As mentioned, a VBS is currently used in Southampton; the port of Vancouver has also designed a Container Terminal Scheduling (CTS) system, which is in use since 2001. Navis, one of the leaders in yard management software for container terminals, has recently introduced the so-called Flow Appointment Scheduling module in its products. With respect to the literature, this approach has been recently analyzed by Giuliano et al. (2006) and Morais and Lord (2006).

We propose an appointment system based on soft time windows: the terminal might trade with transporters arrival and departure time windows; rather than imposing fixed constraints that the planning algorithm of transporters must comply with, the terminal could trade a cost for its violation. Soft time windows do not represent constraints but rather preferences about the time at which visits should occur. Eventually we may think to time windows violation the other way round: the terminal ensures the best performance (that might be based on a contract) within the time window. Outside the time window no guarantee is given (which is the current situation).

Transshipment If we assume that terminals are able to trade with transporters on arrival time and position, a new class of optimization problems arises. In particular, it would be interesting to improve the efficiency of yard operations in a transshipment hub by taking into account the peculiarities of the transshipment containers flow when arrival time and position (berth) of feeders are not known in advance but can be decided by the terminal.

At the best of our knowledge, the typical planning approach is hierarchical: first, the schedule of ships is determined at tactical level; then, berth allocation is determined accordingly to the ships' schedule; finally, yard-blocks allocation is determined accordingly to the berth allocation plan.

We propose a wider view of terminal dynamics, especially with regard to the relationships of the terminal with its partners. It would be interesting to find the optimal berth-yard allocation performing a global and simultaneous optimization. Benefits would be many: we would have control on the distance covered to transship containers from mother vessels to feeders; we would also have control on the workload balance among yard blocks and we would finally have control on the congestion within the yard.

6 Conclusions

In this work, we review the OR literature of decision problems related to the management of container terminals and we outline the trend of the literature for the next future. We present two case studies and we describe some critical issues concerning two container terminals we visited.

We believe that congestion and traffic issues will be more and more relevant in the next future, especially considering the percentage increase of the volume of container traffic. We have directly seen on the field that the service demand is characterized in concentration of loading and unloading operations and a high utilization of shared resources. This will be of more critical impact if we consider that equipment failure may happen with the risk of a blockage of a relevant part of terminal's operations.

We suggest a new approach in the management and planning of operations, which should take into account, in our opinion, possible interactions (and even collaborations) between the terminal and the other market players directly involved in the decision-making process. In particular, under the assumption that arrival time can be negotiated with final transporters (feeders for transshipment hubs and trucks for import/export hubs), the terminal could gain in efficiency by having more control on congestion and traffic issues.

Acknowledgments

We would like to thank Dr. Thierry Vanelslander (Department of Transport and Regional Economics, University of Antwerp), Thierry Vantomme (Commercial manager, DP World), Ing. Carmine Crudo (Accounting, quality and statistic manager, Medcenter Container Terminal), Prof. Manlio Gaudioso and all the OR group (Dipartimento di Elettronica Informatica e Sistemistica, Università della Calabria) for the very fruitful and instructive discussions and visits to the University of Antwerp, the port of Antwerp, the port of Gioia Tauro and the University of Calabria.

We further acknowledge Thierry Vantomme for his valuable comments concerning Section 4. This section of the paper has been updated with respect to the previous report TRANSP-OR 071204.

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