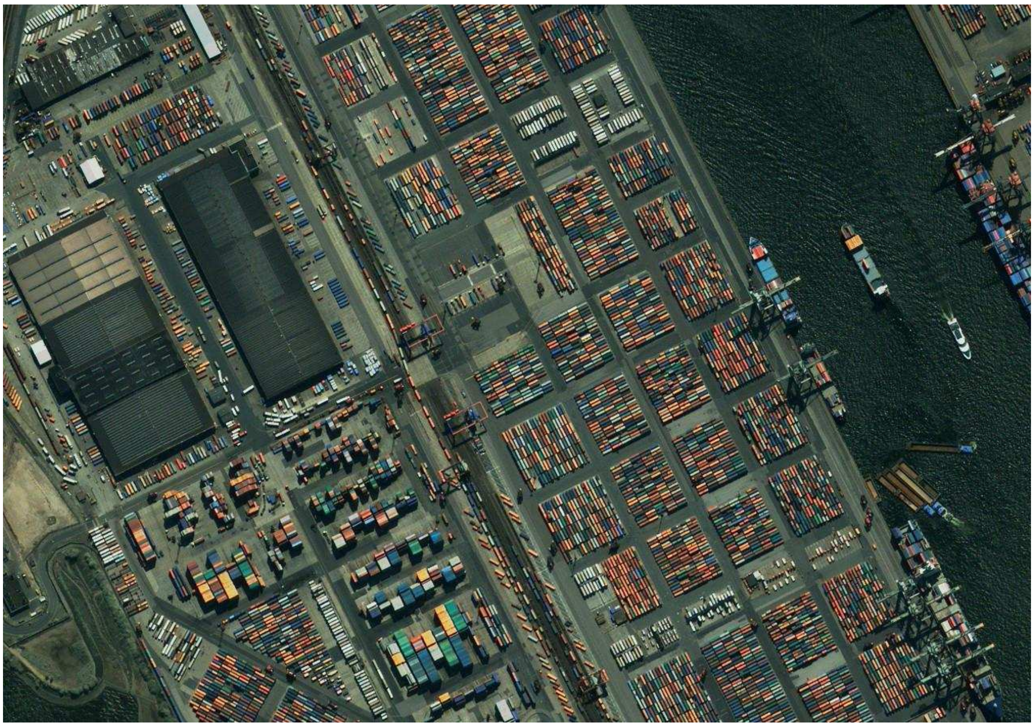

Optimization at Container Terminals: Status, Trends and Perspectives

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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 first 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). Then, starting from a collaboration with some of the busiest ports in Europe, we have identified some critical issues which will be illustrated: in particular, we focus on the impact that gate operations and transshipment operations have on the yard and we propose a new approach to the yard management which takes into account these interactions. We conclude with suggestions of possible research tracks and open issues.

Keywords

maritime transportation – container terminal operations – transshipment – operations research

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 last three years.

Worldwide		2004	2005	2006
1	Singapore	21,329,100	23,190,000 (+8,7%)	24,800,000 (+6,9%)
2	Hong Kong (China)	21,930,000	22,602,000 (+3.0%)	23,230,000 (+2,7%)
3	Shanghai (China)	14,550,000	18,084,000 (+24.3%)	21,700,000 (+20.0%)
Europe		2004	2005	2006
1	Rotterdam (Netherlands)	8,291,000	9,287,000 (+12.0%)	9,690,000 (+4.3%)
2	Hamburg (Germany)	7,004,000	8,087,550 (+15.4%)	8,861,804 (+9.5%)
3	Antwerp (Belgium)	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. In intensive yard terminals, containers are stored up to 6-7 levels high with a gap of 40cm between rows, while 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 this context, many of the multi-modality issues are concentrated within terminals 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.

If we take 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, given that 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 (KPI, Key Performance Indicator) need to be identified and employed to evaluate the performance of a container terminal. Clearly defined KPIs allow to adopt decision support systems that optimize objective functions based on such indicators. We 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, such as TEU volume growth (TEUs per year), crane utilization (TEUs per year,

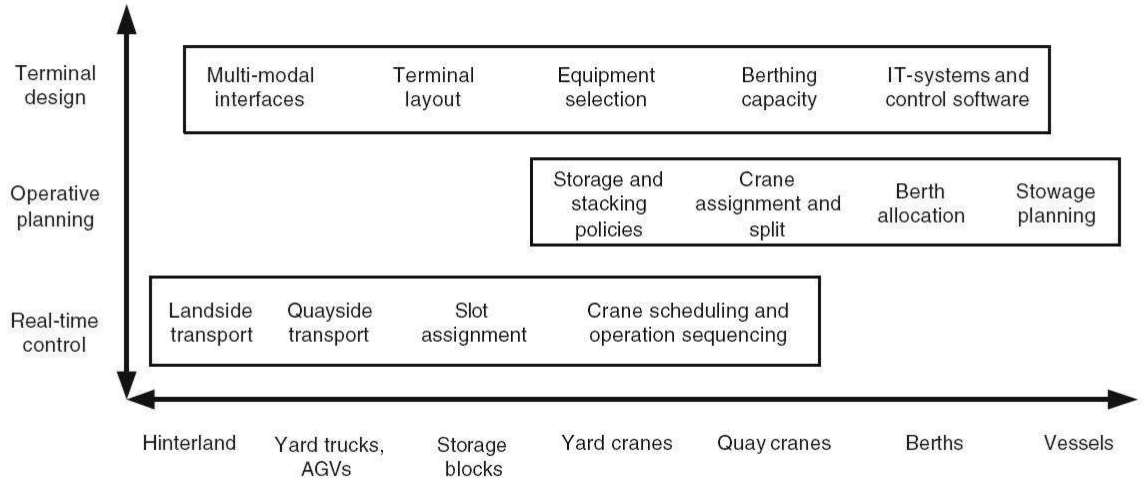

Figure 1: *Planning Levels at Container Terminals (Günther and Kim, 2006)*

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 distinguish three planning levels:

- **Strategic Level** involves long-term decisions regarding terminal layout, terminal equipment, terminal infrastructure, strategic alliances with shipping companies and multimodal interfaces.
- **Tactical Level** involves mid-term and short-term decisions regarding berth and yard templates and storage policies.
- **Operational Level** involves decisions regarding daily and real-time operations such as quayside operations (berth allocation, quay cranes scheduling, ship stowage), landside operations (transfer operations, yard management), empty containers and human resources management.

In this work we review the most recent contributions in the operations research (OR) literature concerning container terminal optimization 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 we intend to investigate.

2 Literature Review

Container terminal operations and their optimization have received increasing interest in the scientific literature over the last years. For an overview of terminal 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 are Kim (2005), Murty et al. (2005), Günther and Kim (2005).

In the remainder of this section we provide a review of recent papers which address common decision problems arising in a container terminal.

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 plans 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 services periodically calling 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.

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 multi-commodity 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 quayside 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 may identify 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.
Moccia et al. (2006) and Sammarra et al. (2007) are specializing the quay crane scheduling problem.
Imai et al. (2003), Imai et al. (2005), Imai et al. (2008) and Imai, Nishimura, Hattori and Papadimitriou (2007) investigate the berth allocation problem under different scenarios.
Finally, 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) model almost all possible yard operations.

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 scheduling.
Bish et al. (2001) and Kozan and Preston (2006) propose some 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

We discuss here two examples of container terminals in the ports of Antwerp (Belgium) and Gioia Tauro (Italy).

4.1 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 17 ship-to-shore (STS) gantry cranes, 2 automated rail mounted cranes (RMGs), 35 straddle carriers (SCs), 1 RMG for the on-dock rail terminal. The quay length is 2500m. Its current capacity is 3.1 million TEUs, but it will reach 3.5 million TEUs as from 2010, because of the conversion of the straddle carrier zone to automated RMGs (up to 96 RMGs will operate in the yard). Further planned developments include 3 additional STS gantry cranes and 6 mobile barge cranes.

This terminal 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 current capacity of the yard is 16200 containers and the average dwell time is about 5-6 days. As mentioned, the yard stacking equipment is being changed from straddle carriers to automated RMGs: with this conversion the terminal will gain an additional capacity of 400000 TEUs, 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 their experience, when the yard utilization is more than 75% of the total capacity, the productivity significantly decrease because of reshuffling.

A mother vessel is usually unloaded and loaded again within 24h; in average about 2400 moves (load/unload) are performed for each mother vessel.

The main costs for the terminal are divided as follows: 50% manpower, 25% fuel and electricity, 25% maintenance costs.

Common practices and issues. The terminal has no control on the gates (especially on the arrival process of trucks) and on barges. Operators do not know in advance which containers are going to be picked-up and when. Without information, optimization is almost impossible. The terminal is therefore trying to implement a so-called Vehicle Booking System (VBS), although truck companies are reluctant to accept this system. 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.

Currently, the routes of trucks inside the terminal are not controlled or planned by the terminal. Once the truck is admitted into the terminal, it decides where to go and then communicates its position to the terminal; there it waits for the (un)loading operations (operated by the straddle carriers). This procedure is inefficient because traffic congestion at the gates usually occurs: trucks arrive almost at the same time and it may happen that the placement at the gates is far from the position of containers in the yard. As a consequence, SCs have to travel a long distance to serve the trucks and they might interfere among each other.

Minimizing the total distance covered by containers from quay to yard is an objective which makes sense for the terminal managers, given that fuel and maintenance costs account up to 50% of the overall terminal costs. They usually assign 3 SCs to each quay crane during (un)loading operations because they don’t want the quay crane to stand idle: in order to create a “cycle”, the 3 straddle carriers cannot go too far away to store/retrieve containers (straddle carriers have a speed of about 30Km/h).

Barges and feeders slow down the operations in the terminal; as they don't have a predetermined schedule, they can arrive at any time without any order. Sometimes barges have to (un)load only few containers: in this case the duration of berthing operations is much larger than the duration of (un)loading operations (a barge can berth in about 15 minutes). This can really become a bottleneck, because resources (berths, cranes) stand idle a lot of time.

It doesn't happen that feeders/barges start to be loaded while the mother vessel is still being unloaded. This is because containers for the same barge are not always stored close in the ship, so a barge may have to load the first and the last containers unloaded from the mother vessel. That's why they prefer to come to 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. The consequence is that all the operations and the planning depend on the mother vessel. The objective is to provide what is written in the contract: 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.

The planning software used by the terminal is Cosmos. All the operations are integrated in a single module but additional specific ad-hoc modules are difficult to obtain and at a high cost. The identification of the container at the gate is not automatic.

4.2 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. Terminal's 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 (4 million TEUs are expected in 2007).

The terminal can handle mother vessels up to 350m long carrying 8000 TEUs. Feeders also have bigger dimension and impact: they may vary from 200-300 moves for the common feeders up to 1000 for dedicated feeders. Usually transshipped containers are not exchanged between 2 mother vessels but between a mother vessel and several feeders. Berthing planning is performed offline.

The terminal is experiencing a high congestion of the yard (utilization was about 90% at the moment of our visit to the terminal) due to a lengthening of the average dwell time, which is currently 8 days. 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: while during 2006 the average crane productivity was 25-26 moves/h, in the first half of 2007 it has decreased to 18 moves/h.

The planning software used by the terminal is Cosmos for the operational decisions, which have to be taken in real-time, while for tactical decisions they integrate Cosmos with some decisional tools internally developed.

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 we intend to investigate in the future. We believe that an increase of the knowledge on these issues would lead to an enrichment of the decisional tools offered to key actors of container terminals.

Tactical level. We propose to define a new class of decision problems which integrate the tactical and the operational planning levels.
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 think it's worth investigating a possible embedding of tactical decisions in the solutions of operational problems.
As a complementary approach, we plan to take into account operational constraints (in terms of rules, common policies and best practices) in the solution of tactical problems: this would enable us to introduce the concept of robustness 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 between market players who trade their businesses acting around maritime transportation. We think that a better understanding of these relations and of how they impact on the 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 (when yard utilization reaches the 90% of the capacity like in Gioia Tauro).
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.

We intend to explore the game theory and pricing policy fields. Recently some work in this direction has been 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.

We also intend to investigate vehicle appointment systems and their impact on gate operations. 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 recently been 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 or it exploits dedicated lanes for the delivery. Outside the time window no guarantee is given (which is the current situation).

6 The transshipment problem

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, we are interested in improving 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 is 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. We aim 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.
We assume that the terminal can decide the order of arrivals of feeders: in this way we can introduce the time variable, which allows the berthing position of feeders to become a variable as well. This approach is pretty original, since the yard position of transshipment containers addressed to feeders is usually the only variable taken into account in the yard optimization literature.
We plan to design a model, study the complexity of the problem and, at the same time, investigate decomposition approaches able to address large scale problems. We believe that this problem is strongly NP-Hard as it embeds assignment and scheduling problems. We suggest the following 2-level approach for the solution:

1. we assign the optimal [berth, block] combination to each feeder, given the associated group of containers;
2. we schedule the arrivals of the feeders.

These two stages are iterated in a process which aims to optimize a global objective function that considers both yard and feeders.

6.1 Berth & Block Allocation Problem (BBAP)

We start considering a simple case: one mother vessel which provides containers to several feeders. For simplicity some assumptions are needed. In particular, feeders only load containers (no unloading operations); feeders receive containers only from the mother vessel we are considering; berths are dedicated to the feeders.

The inputs of BBAP are:

- 1 mother vessel,
- a set of feeders K indexed by $k = 1, ..., |K|$,
- a set of berths J indexed by $j = 1, ..., |J|$,
- a set of yard blocks I indexed by $i = 1, ..., |I|$,
- the distance c_{i0} between the mother vessel and the yard block i,
- the distance c_{ij} between the yard block i and the berth j,
- the demand d_k of feeder k,
- the capacity q_i of block i,
- a time window of length T which is the time allocated to complete all loading operations,
- the time t_{ij} needed to load a container stored in block i onto a feeder berthed at berth j; t_{ij} is composed of a constant time t_l which is the time needed by the quay crane to load the container onto the feeder plus a variable time which depends on the distance between the block and the berth.

The goal of the BBAP is to determine the berth to be assigned to each feeder and the block to be assigned to each container group (identified by the feeder), in order to (i) minimize the total distance covered to transship all containers (it could be the distance block-feeder or other distance measures), (ii) balance the workload among blocks during the storage phase (final distribution of containers in the yard) and (iii) minimize the congestion in storage operations (in this case we also need to know the unloading sequence of containers or at least the time after when a certain container group is available).

We intend to generate a network associated with the transshipment problem and solve an integer multicommodity flow where each commodity represents a container group. The transshipment network (Fig. 2) has the following properties:

- the container group associated with a given feeder k represents a commodity also indexed by k (we assume that there exists exactly one container group for each feeder);
- each feeder k has a demand d_k of commodity k and a demand equal to zero for all the other commodities;
- nodes associated with blocks and berths are transit nodes;
- node 0 is associated with the mother vessel and it is the single source of all flows (total offer is $\sum_k d_k$);
- arcs $(0, i)$ have cost equal to the distance between the mother vessel and block i; the max capacity of this arc is equal to the capacity of block i;

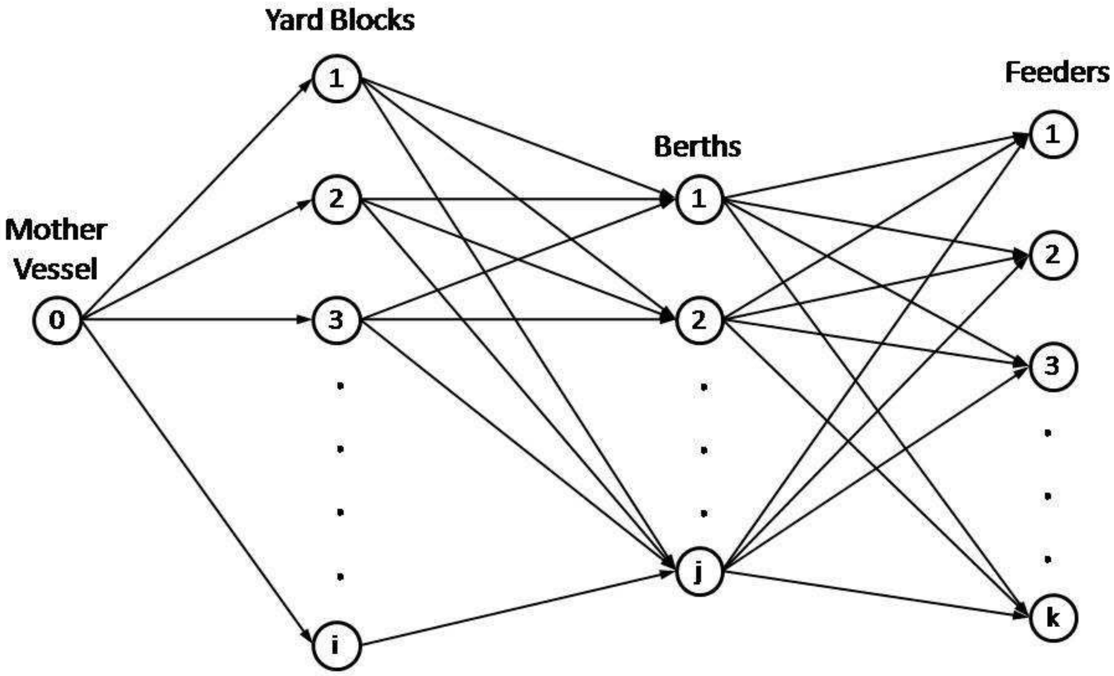

Figure 2: *Scheme of transshipment network*

- arcs (i, j) have cost equal to the distance between block i and berth j; the max capacity of this arc is equal to T/t_{ij};
- arcs (i, k) have cost equal to 0 and capacity equal to d_k.

6.2 Scheduling of feeders

The solution of BBAP is used as input for the scheduling of feeders. We assume we are given:

- the list F_j of feeders assigned to berth j,
- the block position $i \in I$ of the container group k associated to feeder k,
- the demand d_k of feeder k,
- the time window T,
- the time t_l needed to load one container onto a feeder,
- the time t_b needed to the berthing and departing operations of a feeder,
- (optional) priorities assigned to feeders.

Our goal is to find a feasible berthing schedule for each berth, i.e. to sequence the feeders assigned to the same berth, for all berths, in order to minimize the congestion during retrieval operations and maximize the utility associated with priorities, if given. It could happen that we don't find a feasible scheduling. Techniques must be investigated in order to keep the optimality in the BBAP and reach the feasibility in the scheduling. We plan to consider also global objective functions that can be addressed with a similar approach.

7 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. In particular, 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 present some potential research directions and we outline a possible different approach to yard management where terminal authority can negotiate the arrival time and position with final transporters (feeders for transshipment hubs and trucks for import/export hubs).

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