Optimization of Container Terminal Operations

Ilaria Vacca, Michel Bierlaire, Matteo Salani

Transport and Mobility Laboratory
École Polytechnique Fédérale de Lausanne

5th Joint OR Days - Zurich 27.08.2007
Outline

- Introduction
- Terminal overview
- Terminal operations
- Yard optimization
- Transshipment
- Conclusions
Introduction

- Growth of container sea-freight transportation

- Competition among terminals in terms of:
  - Service (ship’s turnaround time)
  - Productivity (TEUs per year)

- Issues: traffic, congestion and capacity limits

- OR techniques to improve the efficiency of terminal operations
Terminal Overview
Terminal Operations

- **Ship-to-Shore**
  Berth Allocation; Quay Cranes Scheduling; Ship Loading Plan.

- **Transfer**
  Quay-Yard; Yard-Yard; Yard-Gate.

- **Storage**
  Yard Management (Block and Bay Allocation); Yard Crane Deployment

- **Delivery and Receipt**
  Gate management; Interface with trains and trucks.

In addition to the traditional flow: transshipment containers, empty containers and human resources management.

*Vis and de Koster (2003); Steenken et al. (2004); Henesey (2006)*
Yard Overview

The yard serves as a buffer for loading, unloading and transshipping containers.

The yard is separated into blocks. The position of the container inside a block is identified by bay, row and tier.
Yard Optimization

- **Storage policies** for groups of containers at block and bay level, in order to:
  - balance the workload among blocks;
  - minimize the total distance covered to shift containers from quay to yard.

  *de Castilho and Daganzo (1993); Kim et al. (2000); Kim and Park (2003); Zhang et al. (2003); Kim and Hong (2006); Kang et al. (2006); Lee et al. (2006).*

- **Re-marshalling of containers** according the ship loading plan, in order to:
  - speed-up loading operations and thus minimize ship’s turnaround time.

  *Kim and Bae (1998); Lee and Hsu (in press).*

- **Yard cranes deployment** (allocation of cranes among blocks, routing and scheduling of operations), in order to:
  - minimize the completion time of jobs.

  *Kim and Kim (1997); Linn et al. (2003); Zhang et al. (2002); Kim et al. (2003); Ng and Mak (2005); Ng (2005); Kim et al. (2006); Jung and Kim (2006).*
Issues in Yard Management

The yard is usually the bottleneck of the terminal. Traffic, congestion and capacity issues originate from here.

Main issue: the “schedule” of the outgoing flow is unknown to the terminal.

- Import/export terminals: yard management is strictly connected to gate operations (trucks and trains).
- Transshipment terminals: yard management is strictly connected to mother vessels and feeders.
Transshipment

- Players in transshipment: mother vessels and feeders;

- Peculiarities of the transshipment flow:
  - known arrival and departure positions;
  - known arrival and departure times;
  - concurrency of loading and unloading operations.

- Definition of new transshipment-related problems:
  - Service Allocation Problem (Cordeau et al., 2007);
  - Group Allocation Problem (Moccia and Astorino, June 2007).
  - Short Sea Shipping: recent study on barge rotation planning in the port of Rotterdam (Douma et al., June 2007).
The Service Allocation Problem

Cordeau et al. (2007)

- Tactical problem (3-month horizon) arising in yard management of transshipment terminals (case study: port of Gioia Tauro, Italy);
- A service (also called port route) is the sequence of ports visited by a vessel;
- Services periodically call at the terminal: they need to be assigned a favorite area along the quayside and in the yard;
- Service allocation has an impact on the number of handling operations inside the yard (housekeeping).
The Service Allocation Problem

- $N$, the set of services, $|N| = n$;
- $M$, the set of bays, $|M| = m$;
- $t_{ij}$, the traffic intensity between service $i \in N$ and $j \in N$;
- $q_i$, the space requirement of service $i \in N$;
- $Q_k$, the space available at bay $k \in M$;
- $c_i$, the average number of crane moves required for service $i \in N$;
- $C_k$, the average number of crane moves allowed at bay $k \in M$;
- $M(i)$, the set of feasible bay assignments for service $i \in N$;
- $d_{hk}$, the distance between bay $h \in M$ and bay $k \in M$.

$$x_{ik} = \begin{cases} 1 & \text{if service } i \text{ is assigned to bay } k; \\ 0 & \text{otherwise.} \end{cases}$$
The Service Allocation Problem

\[
\begin{align*}
\min & \quad \sum_{i \in N} \sum_{j \in N} \sum_{h \in M} \sum_{k \in M} t_{ij} d_{hk} x_{ih} x_{jk} \\
\text{s.t.} & \quad \sum_{k \in M(i)} x_{ik} = 1 \quad \forall i \in N, \\
& \quad \sum_{i \in N} q_i x_{ik} \leq Q_k \quad \forall k \in M, \\
& \quad \sum_{i \in N} c_i x_{ik} \leq C_k \quad \forall k \in M, \\
& \quad x_{ik} \in \{0, 1\} \quad \forall i \in N, \forall k \in M.
\end{align*}
\]
The Group Allocation Problem

*Moccia and Astorino (June 2007).*

- Operational problem arising in yard management of transshipment terminals (case study: port of Gioia Tauro, Italy);
- A container group is a set of container of same type, same origin, same destination;
- Arrival/departure times and arrival/departure positions along the quay are known in advance (input: Berth Allocation Plan);
- Objective: minimize housekeeping.
Transshipment: A New Approach

- Several players: terminal, mother vessels and feeders;
- Negotiation between terminal and feeders on the arrival time;
- Integration of berth and block allocation;
- Objectives: minimize total distance quay-yard; minimize congestion in yard blocks; balance workload among blocks.

Research plan on 2 levels:

1. Optimization framework for the simultaneous assignment of berths and blocks with feasible scheduling of feeders;
2. Definition of ad-hoc pricing policies to support the terminal in the negotiation with feeders.
Conclusions

- OR techniques are worth being applied to improve the efficiency of terminal operations.

- Focus on yard management and its interactions with:
  - gate operations;
  - transshipment flow.

- A new approach in the management of transshipment operations.

- Investigation of possible negotiation and cooperation between the terminal and the other market players.
References


Moccia, L. and Astorino, A. (June 2007). The group allocation problem in a transshipment container terminal (working paper), *World Conference on Transportation Research, Berkeley*.


