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Jürgen W. Böse *Editor*

Handbook of Terminal Planning

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To my daughter Florentine

Preface

The *Handbook of Terminal Planning* is a collection of individual contributions that deal with selected issues in the context of the suprastructure planning of seaport container terminals. It thus has the character of an anthology in which chapters are contributed by an international authorship.

Seaport container terminals form a bimodal or trimodal interface of water-, rail- and road-based transport systems. If the function of the interface is limited to a bimodal cross-linking of transportation systems, such terminals typically enable a connection of container sea transport in the main run with road transports in the pre- and on-carriage of the intermodal transport chain.

The main tasks of terminal planning on the level of suprastructure comprise layout design, quantitative dimensioning of terminal resources and the derivation of requirements for single suprastructure elements considering given operator requirements for the entire terminal. Requirements engineering usually starts with the elaboration of (necessary) functional properties which are specified in the course of the planning process and are eventually ’translated’ into specific technical and process-related requirements. In later project phases, the results of suprastructure planning form the basis for the equipment procurement process, construction measures and the commissioning of projected terminal structures.

The success of suprastructure planning is primarily measurable by the extent elaborated planning results may create the necessary prerequisites so that (later) day-to-day operation fulfills existing requirements. The latter are especially derived from the site conditions of the particular terminal and the target system of the terminal operator.

The contributions of the Handbook give an overview of important technological and organizational system basics from a planning point of view. They also describe promising analysis and planning approaches for typical problems of the suprastructure planning and discuss instrumental issues of planning support.

This book is the result of time and effort of many, who have participated in the creation process, partly directly and indirectly, with great energy and (hopefully) also joy. I thank the authors of the chapters that have contributed to the success of the project through their commitment and professional co-operation. I would also like to thank Mrs. Melanie Engelhardt and Mrs. Marie-Luise Stünkel for their dedicated and flexible service in the linguistic correction of the contributions and for the rendered translation work.

Special thanks go to my wife, Birgit, who accompanied the creation process of the book with much patience. Her courageous participation in numerous day and night shifts in the final phase of the book project has significantly contributed to the existence of this anthology today. Likewise, special thanks go to my mother and my grandmother, who supported me all my life with huge energy and all available means and without whose backing this book as well as much else in my life would not have been possible. The *Handbook of Terminal Planning* is dedicated to my daughter Florentine who accompanied me on my path of life as a bright sunshine for just over one year.

Hamburg,
October 2010 *Jürgen W. Böse*

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Part I
Introduction

Chapter 1
General Considerations on Container Terminal Planning

Jürgen W. Böse

1.1 3-Level-Model

Due to the immense increase of international container traffic in recent decades the solution of capacity problems was in the center of interest for many years among of all involved parties, *i.e.* common action strategies were usually orientated towards growth. That behavior applied to the public and political instances in charge (see, *e.g.* JWP (2010) or PoR (2010)) just as for the companies of the container transport and handling industry. The logistics service providers directly contributing to the intermodal transportation chain should be especially mentioned in this regard, *e.g.* shipping companies, terminal operators or transport service providers of the terminal hinterland like rail transportation companies and cargo forwarding companies (see, *e.g.* HHLA (2010) or Maersk (2010a)).

During the current decade, the continuously rising handling volumes and increasingly higher standards for protection of the environment additionally force the companies to pay more attention to environmental effects of their operational activities (see, *e.g.* Maersk (2010b)). For seaport container terminals, topics such as *air*, *noise* and *light pollution* or *modal split* of hinterland transports (*i.e.* share of rail, truck and barge container) are the ones that gained in importance and which the terminals are confronted with by the executive public authorities, *e.g.* port authorities (see HPA (2010)). Accordingly, environmental aspects and sustainable objectives in the context of seaport container terminal planning had a growing importance in recent years.

Especially triggered by the (first) deeper crisis of the international container traffic in the last (two) years, on the side of many logistics companies of the branch capacitive objectives were now pushed into the background and were replaced in their

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priority (in part abruptly) by cost-related objectives – frequently associated with dramatic activities for cost savings (see, *e.g.* HHLA (2009)). Today, the focus of many seaport terminal operators primarily is on measures that promise a more economic service, ideally combined with a highly flexible use of available capacities. The result of all the efforts shall increase the ability to better react to the increasingly dynamic market requirements concerning *price* (*e.g.* handling charges), *quantity* (*e.g.* annual terminal throughput and volume per call), *time* (*e.g.* container dwell times) and *space* (*e.g.* network of hinterland destinations). Of course, the outlined shift of the target system of many terminal operators has also influenced activities of seaport container terminal planning, *i.e.* the problems to be solved and planning solutions promising successful results.

Fundamental tasks of container terminal planning (at sea- and inland ports) are discussed in further detail based on a level-model developed in this contribution. The area of responsibility particularly includes all planning activities regarding objects relevant to the conception, construction and operation of a terminal. Planning generally means an object-related (theoretical) anticipation of planning alternatives forming the basis for an evaluation and prioritization of alternatives by considering expected effects of realization and defined (project) objectives.

Taking into account the nature and time-related impact (*i.e.* planning horizon) of planning objects, these may be assigned to different ‘levels’ in the scope of container terminal planning, called *planning levels*. Basically, the ‘planning levels’ are divided into *Planning of Terminal Operations*, *Planning of Terminal Suprastructure* and *Planning of Terminal Infrastructure* (see Figure 1.1). Planning activities, decisions and measures (associated with task processing) refer to the different levels of terminal planning as follows:

- **Planning of Terminal Operation**
  It focuses on the short-, medium- and long-term planning of operational (*i.e.* container handling, transport and storage) and administrative terminal processes. Accordingly, the related planning decisions and measures once again can be broken down into three additional ‘sub-levels’.
  - *Short-term Planning*
    operational decisions and measures especially for the organization of day-to-day operation.
  - *Medium-term Planning*
    tactical decisions and measures, among others, in the field of outsourcing activities (*e.g.* IT support), the basic use of terminal resources (*e.g.* shift system or strategies for equipment control), or inter-organizational co-operations (*e.g.* labor pooling with other terminals).
  - *Long-term Planning*
    strategic decisions and measures regarding terminal operation such as the range of terminal services (*e.g.* vessel sizes considered for handling at quay and vessel size-related commitments to handling times) or long-term partnerships (*e.g.* establishment of dedicated berths based on strategic co-operation agreements between terminal operators and shipowners)

- **Planning of Terminal Suprastructure**
  It particularly includes activities for requirements engineering and quantitative dimensioning of terminal resources. Among others, decisions and measures have impact on the layout design, manning requirements, terminal buildings, operations equipment, and the supply & disposal network. Elaborated planning results form the basis for procurement, construction and commissioning of terminal suprastructure. In the context of suprastructure planning it is determined what kinds (types) of resources are used in which quantity for the provision of terminal services. Typically, planning needs on the suprastructure level are induced by 'greenfield projects' or strategies for 'terminal expansion' and 'conversion of handling technologies'.
- **Planning of Terminal Infrastructure**
  It deals with decisions and measures regarding the preparation of the terminal area (*e.g.* area size and altitude, quay wall length) and the terminal connection to external networks (traffic, energy and supply & disposal). Planning activities on this level, among others, relate to the fields of land reclamation, sand dredging, construction of quay wall and external traffic routes and the linking of terminals to public transportation networks, respectively.

As regards seaport container terminals planning activities on the *level of terminal operations* and *terminal suprastructure*, these are usually the responsibility of terminal operators, as they must also finance the implementation of related measures. As a result, terminal operators have a direct influence on the design of real world objects belonging to these planning levels. Planning of terminal infrastructure usually is the duty of local communities and authorities and accordingly is supported by them financially. Thus, terminal operators cannot (or only indirectly) enforce planning decisions regarding the terminal infrastructure (see Figure 1.1).

The planning activities and elaborated planning results on the different levels may not be seen independently. There are interdependencies between them, resulting in a natural (hierarchical) order of the planning levels, which shall be explained in the following.

The achieved planning results on the *level of infrastructure planning* define a kind of basis for action for the two other levels, by providing support (and also restrictions) for planning on these levels. The same applies to the planning results on the *suprastructure level*, which represent in this regard a direct basis for activities on the *level of operations planning*.

On the other hand, planning activities, that have been carried out on a certain planning level, generate requirements for the subjacent level(s), *i.e.* these levels have to provide support enabling the realization of planning objectives on the overlying level(s). If support services are not available to the required extent, the supporting impact changes to a restrictive impact and limits the planning action on the overlying level(s) as restriction. Originating from the *level of operations planning* requirements can be basically defined for the *level of suprastructue planning* and further for planning on the *infrastructure level*. From the described interdependencies a hierarchical level structure for the tasks of container terminal planning can be derived, which is shown in Figure 1.1.

In case of an "imbalance" of support services and requirements between two levels because of unfulfilled planning requirements,[1] there is the need for a (basic) change in planning on the subjacent level(s) – if planning objectives on the upper level shall be realized in terminal practice.

Example: Due to changes in market requirements an extension of terminals services becomes necessary as regards the handling capability of vessels belonging to the super post-panmax class (*strategic operations planning*) -> replanning of quayside terminal equipment, *i.e.* procurement of super post-panmax quay cranes, for instance (*suprastructure level*) -> planning of reinforcement of quay wall construction due to increased wheel loads of quay cranes (*infrastructure level*).

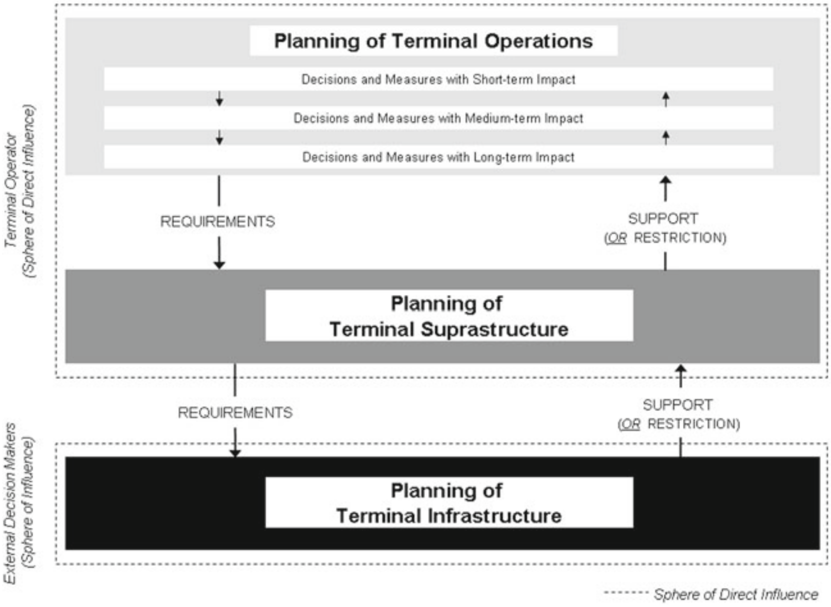

Fig. 1.1 3-Level-Model of Terminal Planning (overall dependencies)

In addition to the structuring of terminal planning by different levels, it makes sense to keep structuring planning tasks on the single levels based on the main operations areas of a container terminal (quayside, yard and landside, see Section 1.2). Due to the interface character of such facilities the sea- and land-based access to deep-sea or hinterland transportation systems respectively should also be considered for this purpose (see Figure 1.2). Analogous to the (described) overall relationships also appropriate interdependencies (*i.e.* planning requirements vs. planning support) can

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[1] *I.e.* planning results of the lower level are to be understood as restriction (and not as support) for planning on the upper level.

be identified between the different operations areas and their connection to terminal environment on the same level.[2] A general (directional) orientation of the relationships, however, is not given or is less clearly distinct here, so that existing interdependencies on the levels have to be specified separately in terms of their nature and direction for each application case.

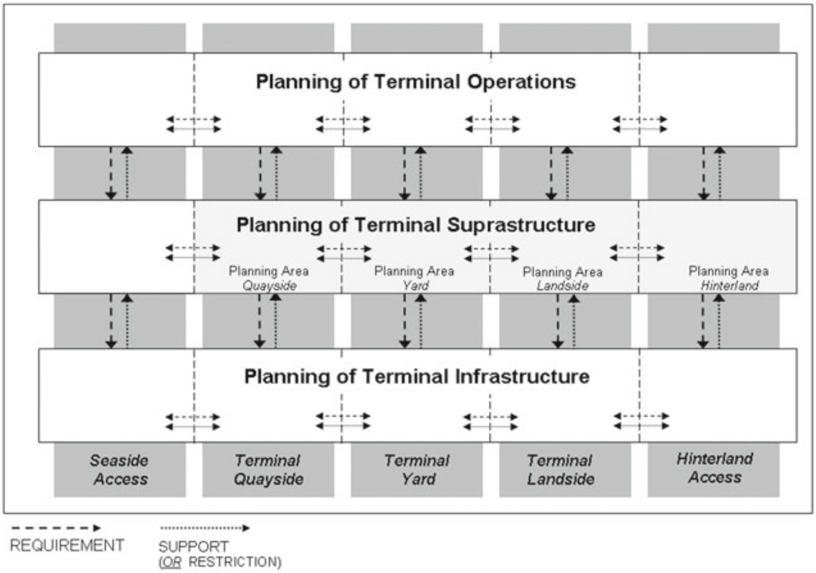

Fig. 1.2 3-Level-Model of Terminal Planning (level-related dependencies)

On the *level of terminal operations planning*, for example, time and volume requirements generally originate from the terminal quayside because of the dominance of shipowners in international container transports. From there, they directly turn to the adjacent yard area and indirectly to operations activities on the terminal landside. In contrast to that, planning requirements between the operations areas on the *planning level of suprastucture* particularly derive from the functional, technical and economic properties of the used handling, transport and storage technologies, so that usually no fundamental directional orientation can be identified in this regard.

Example: On the one hand, perpendicularly oriented container blocks within the yard area induce – due to economic reasons – requirements regarding the type of equipment for horizontal transport at quayside (to favor: *A*utomated *G*uided *V*ehicles (AGVs) or straddle carriers). On the other hand, the container volume handled by quay cranes in peaks requires a minimum number of yard cranes serving quayside appropriately, *i.e.* without operational delays.

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[2] The planning tasks of each operations area on each level of the model shown in Figure 1.1 and 1.2 are combined to so-called *planning areas* for structuring purposes, see Section 1.3.

Keeping in mind the various *levels of terminal planning* it shall be emphasized that the Handbook with its contributions focuses on planning tasks on the *suprastructure level* of seaport container terminals (see Figure 1.2). In this regard, special attention is particularly given to problems and (solution) approaches in the field of *equipment* and *layout design*, as well as issues of an effective connection and development of terminal hinterland.

1.2 Basic Aspects: Technologies & Instruments

A fundamental prerequisite for the production of competitive planning results is the knowledge of possible action alternatives. Regarding *suprasturcture planning* of seaport container terminals, this particularly includes information about available suprastructure and its functional and economic properties or impact, respectively. The following categories of suprastructure elements are frequently distinguished by (see, *e.g.* Zachcial et al (2006)):[3]

- container handling, transport and stacking equipment
- terminal area: pavement, area partitioning (layout), illumination, fencing, etc.
- terminal buildings and
- supply & disposal network

It should be mentioned that only the terminal equipment (and "human labor") enables the flow of containers between the seaside and landside interfaces (*i.e.* railway station and/or truck gate and/or barge terminal) in an active manner and therefore contributing directly to the physical connection of the various transportation systems. Thus, the handling machinery may be considered as an integral part of the operational activities and processes of container terminals.

Based on the kind and extent of operational activities the terminal may be subdivided into different operations areas with related activities (or their results respectively) as their logistic functions. In this regard, a basic distinction can be made between the *quayside*, *yard* and *landside operations area* of a container terminal providing the following functions.

Quayside operations area

- vessel discharging and loading
- container handover between terminal equipment
- horizontal container transport between quay cranes and the full / empty container yard

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[3] In this Handbook – in a somewhat broader sense – the factor "human labor" as well as IT systems used by the terminal are explicitly rated among suprastructure and regarded as relevant sub-/objects of suprastructure planning.

Yard operations area

- container transport and stacking within the yard area
- container handover between terminal equipment

Landside Operations area

- horizontal container transport between the main / empty yard and handling areas of hinterland means of transport (barge terminal, railway station, truck holding area / handling positions)
- container handover between terminal equipment
- container transport and stacking within the empty yard
- unloading and loading of hinterland means of transport
- physical check of in-/outbound containers as well as check of container data

Only through a systematic (*i.e.* well-planned) combination of all logistic functions, a container terminal is able to fulfil its overall function as system interface of international transportation networks. Logistic terminal functions and the main container flows (import flow, export flow, transhipment[4]) within the terminal area are shown in Fig 1.3. All of the boxes[5] passing the main yard and the empty (MT) depot of a terminal are taken into account in this consideration and are illustrated according to their occurrence in the main operations areas. For instance, *Break Bulk* and *Out of Gauge Cargo* are explicitly not part of the flow view in Figure 1.3.

Variations in logistic sub-functions in a terminal may arise, for example, by a lack of hinterland connection of the facility (pure transhipment terminal) or by offering value-added services, such as container freight station services.

As already mentioned, specific equipment is used for carrying out the logistic tasks at a container terminal, *i.e.* the equipment is specialized as to its functionality to suit the individual logistic requirements. As a result, its application is frequently possible (reasonable) in certain terminal operations areas (see Brinkmann (Chapter 2 of this Handbook)) due to technical and/or economic reasons.

In view of an adequate *suprastructure planning* it is essential for equipment selection and quantitative sizing of the equipment fleet to know the main properties of the available types of handling equipment. It should be noted that logistics equipment characteristics being relevant for planning decisions frequently only form under the given application conditions (and therefore must not necessarily correspond with the technical specifications of the equipment supplier). In this context device properties of the following areas can be distinguished:

- investment per unit
- manning requirements
- energy consumption per unit

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[4] Transhipment containers exclusively reach and leave the terminal with feeder and ocean-going vessels on the terminal quayside.

[5] *Main yard*: standard container (in particular 20 ft, 40 ft and 45 ft boxes), container with dangerous goods, tank and reefer container.
MT depot: empty container of different sizes.

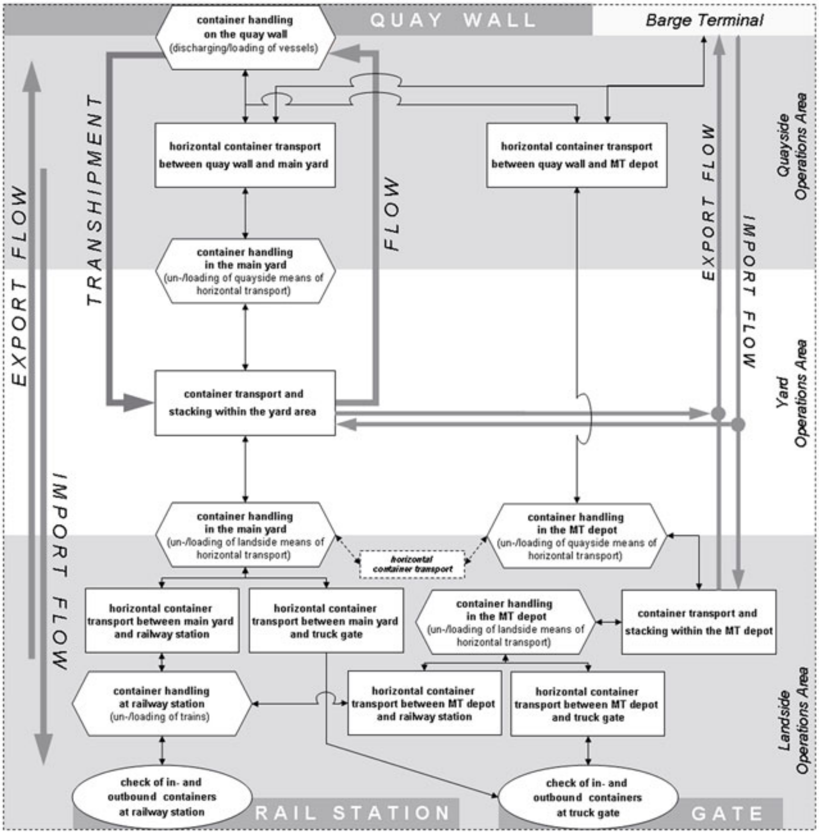

Fig. 1.3 Logistics sub-functions and main container flows of a seaport container terminal

- environmental impact
- productivity characteristics
- maintenance & repair expenditure
- technical lifetime
- operational flexibility (*e.g.* compatibility with other equipment types or versatility regarding their logistic capabilities and operations area)

In this Handbook, various chapters deal with the issue of qualification and quantification of terminal handling equipment on the level of suprastructure planning. They outline logistics, economic and environmental device properties (impacts) and offer valuable guidelines and decision criteria supporting equipment planners to meet the operational requirements. Subsequently, these contributions are referred to in short regarding their content orientation:

The contribution of *Brinkmann* provides an overview of the major determinants of equipment selection, as well as the types of terminal equipment typically used in the main operations areas. Common container handling systems[6] – as a combination of several types of devices – are presented and evaluated in terms of their fundamental advantages and disadvantages.

Against the background of increasing demands from society for a better quality of life and growing environmental problems on the one hand and existing cost and capacity requirements from the market on the other hand *Wieschemann* discusses a design approach for terminal (stack) handling systems merging these partly opposed objectives. The intention is to consider both aspects of sustainability and economic viability. The contribution shows the challenge how to balance service requirements, costs and demands for sustainable designs and operations of container terminals.

The contribution of *Pirhonen* deals with innovative container handling technologies for process automation at the terminal quayside and yard. The presented shuttle carrier® concept is based on automated shuttle carriers in combination with automated rail-mounted gantry cranes for container transport at quayside and storage within the yard area. Pirhonen compares this fully automated handling concept with a conventional system approach using yard tractors and rubber-tyred gantry cranes. The system comparison delivers interesting results in terms of equipment and manning requirements, as well as environmental impacts.

Based on the given insights into handling processes and technologies at container terminals basic aspects of instrumental support for suprastructure planning shall be discussed in the following: In view of the character of planning (as a mental anticipation of future action alternatives), it makes sense to support planning processes with appropriate modeling of envisaged action alternatives, respectively. Created models[7] allow a comparatively cost-efficient representation of reality relevant to the respective planning task. They can be used for the conceptual investigation of given alternatives regarding their impacts on the future application environment and enable *e.g.* the systematic analysis (ideally quantification) of expected cost and performance effects.

Due to the occurrence of fortuitous events and influences the operation of container terminals is inherent a considerable degree of randomness. Consequently, operational terminal processes and the associated use of suprastructure frequently do

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[6] Please note that the terms *container handling system* and *terminal operations system* are used as synonyms in this handbook

[7] *Models* provide images of material and immaterial objects / constructs of reality and the abstract world like ideas, concepts or visions (see, *e.g.* Hangos and Cameron (2001), p. 4ff.). They allow, if necessary, an experimental manipulation of represented structures and states. In modeling often – also within the context of planning – not every element and every relationship between individual elements of the modeling object has a corresponding counterpart within the model. As a result, the (structural) model complexity is naturally smaller than the one of the observed aspect of reality. To do so it proves to be advantageous that relevant aspects of reality are much easier to penetrate within the model (due to reduced complexity) and the information needs resulting from modeling may be severely restricted. As disadvantageous, however, can be seen the necessity to anticipate the extent of complexity reduction (without reducing the meaningfulness of the model significantly). The question to what extent complexity reduction should be strived for can often only be answered after applying the model with assistance of generated solution(s) and their validity. Depending on the pursued model purpose a strong detailedness on the one hand brings about an unnecessary big effort, on the other hand, a high level of abstraction can lead to solving the “wrong problem”.

not have a deterministic character and are – in terms of their (future) outcome – of limited predictability. If the real terminal system has to be modeled in the context of suprastructure planning (*e.g.* for the purpose of equipment planning or layout design), models should – due to the significance (validity) of their application results – be able to reproduce existing uncertainty.

In addition, terminal processes show a dynamic behavior, of course. They usually change their state over time and thus have no static character in the period under consideration. Modeling capabilities of these kinds, *i.e.* possibilities for representation of randomness and dynamic aspects are especially given by simulation models (see, *e.g.* Law and Kelton (2000) or Birta and Arbez (2007)).[8]

In this Handbook, various chapters deal with aspects for instrumental support of suprastructure planning. Subsequently, they are referred to in short regarding their content orientation:

The contributions of *Saanen* and *Schütt* give a comprehensive overview of the support options simulation models provide and which improvements can be achieved through their use in solving planning problems on all levels of terminal planning. In this regard, the advantages of using simulation models in the different phases of "terminal life cycle" are shown, starting from the (initial) *dimensioning of suprastructure* and the phase of *terminal commissioning* up to the *day-to-day operation*. Here, not only problems of equipment and layout planning are discussed, but also possibilities for the use of simulation in functional specification and validation of the terminal IT systems and their optimized configuration regarding the day-to-day operation. Based on this, Schütt additionally focuses on the application of simulation for evaluating ecological impacts and Saanen introduces concrete guidelines for using simulation on the various levels of terminal planning.

Besides the dimensioning of artificial terminal resources, it is up to *suprastructure planning* to also ensure that the availability of the factor "human labor" is in accordance with the demand. Quantitative (manning) requirements of the operational processes particularly derive from the equipment planning, requirements of the administrative area are generally based on experience. In this context it should be mentioned that viability of the terminal IT systems may affect the manning requirements significantly.

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[8] According to the VDI guideline 3633, *simulation* is the "representation of a dynamic process in a model to achieve knowledge that is transferable to the reality" (see VDI (1993)). The main components of such models are variables and relations. Time-related they describe the state of a model by its characteristics.

Model variables are distinguished in input variables (like distributions of external/predefined events) and output variables (*e.g.* interims or final results). They can have a deterministic or a stochastic character. In the latter case, there are so-called random variables, of which property characteristics are determined based on probability distributions enabling the modeling of non-deterministic real-world contexts. In addition, the model variables can – depending on the modeling purpose – be updated continuously or discretely on the time axis. Both allow the representation of dynamic aspects of the reality. In case of continuous models the variables are described over time by means of continuous functions whereas variables of discrete models usually change their state characteristics in an erratic manner.

Model relations characterize the functional relationships between the variables and/or the underlying distribution functions, that determine property characteristics of model variables.

In view of necessary qualification of employees the contribution of *ma-co* presents a modern competence management system, which flexibly supports a vocational education and training of employees working for companies in the logistics industry. The competence management system enables the purposeful conception of qualification measures, resulting in comparatively low cost for qualification of staff in all phases of the container terminal life cycle. In addition, the system represents a common communication basis for all groups involved in education and training measures and can serve as a monitoring tool for the achieved level of education during the implementation of measures.

1.3 Main Planning Areas

Based on the terminal operations areas defined in the previous section a basic distinction of the planning areas *quayside*, *yard*, *landside* and *hinterland* is subsequently made for the classification of tasks and solutions of terminal planning (see also Figure 1.2). For the various areas the main planning tasks on the suprastructure level are described first and the requirements to be considered by planning activities are mentioned. Then, the key aspects of the Handbook articles apportioned to a planning area are presented and mentally categorized in the overall context of the suprastructure planning.

1.3.1 Quayside

On the quayside the dimensioning of quay cranes and the equipment for horizontal transport between quay wall and yard represent the main planning tasks for suprastructure planning in the field of terminal machines. Both kinds of equipment have to be specified according to their nature (by appropriate requirements) and the number of pieces to be procured must be determined.

In addition to equipment issues also the design of terminal layout is seen as a task of suprastructure planning on the quayside. This applies to the container handover area and hatchcover storage in the portal or backreach of quay cranes and the traffic area adjoining the container yard.

Differentiating between preplanning and detailed planning activities on the suprastructure level the former end up with a prioritization of elaborated equipment / layout alternatives and finally leads to type-related suprastructure decisions (*e.g.* use of AGVs instead of shuttle carriers or vice versa). The latter especially includes the specification of functional, technical and process-related requirements for the favored preplanning alternatives. Results of detailed planning eventually form the basis for the tendering process bringing out the equipment supplier(s) and construction firm(s) chosen for the project.

Planning on the suprastructure level is to adjust to numerous (external) requirements especially given by the local terminal conditions, the target system of the terminal operator and already existing suprastructure. In terms of the quayside planning area, among others, requirements in the following manner arise:

- traffic forecast
- vessel call pattern (arrival time, type and number of vessels)
- quay wall layout / construction and depth of water
- quay wall throughput per year
- quay wall throughput in peaks
- degree of automation
- availability of terminal area
- cost restrictions
- yard technology and capacity

The focus of the Handbook contribution for quayside suprastructure planning includes, in particular, analysis and planning approaches regarding problems in the field of quay wall occupation and capacity, layout design and economic viability to be expected for vessels depending on their size.

The contribution of *Hartmann et al.* presents a general simulation model that can be applied to examine the utilization of quay wall with regard to scenarios of expected future workload or vessel arrival pattern, respectively. The model includes a quay with a given length, a decision module for assigning vessels to berths, a waiting queue for vessels without berthing option and a generator of vessel arrivals. The contribution outlines the concept of the simulation model, points out extensions that would be necessary to adapt it to a specific terminal and presents some experimental results based on real data.

The length of the quay and the number of quay cranes are crucial determinants for the handling capacity and the service quality of seaport container terminals. The contribution of *Meisel and Bierwirth* describes a technique to determine the quay crane capacity for a terminal with respect to a projected set of liner schedules of calling vessels. For this decision, they take into account the service quality and cost of the terminal resulting from crane capacity adjustments. A detailed planning model and a related solution method are presented to anticipate the service operations under different crane deployments. Computational tests are conducted to determine the appropriate number of cranes to cope with assumed workload requirements and to identify the most favorable crane assignment strategy.

Besides quantitative dimensioning of terminal resources another major task of suprastructure planning on the quayside is the layout design of the operations. In this regard, the contribution of *Ranau* compares the space requirements of two different automated operations systems: on the one hand, the AGV system which is in use at the Container Terminal Altenwerder in Hamburg and on the other hand, the automated SC system field tested at the Container Terminal on Fishermans Island in Brisbane. Main analysis objects are the quay wall with the quay cranes, as well as the traffic area between these cranes and the container yard.

Being aware of the continuous development in size of container ships *Pawellek and Schönknecht* present an analysis method for quantifying their cost, performance and economic viability in the main carriage of international container transport chains. The analysis results allow terminal operators and public authorities to evaluate assumptions about the vessel sizes calling their ports and terminals in future. The use of larger vessels in international container shipping (partly drastically) increases the requirements to suprastructure and infrastructure for seaport container terminals (and their hinterland). If indicators of such a development are given for ports of a certain region major logistic problems seems to be inevitable for all of those not adapting their handling capabilities on time. As a result, terminals of these ports will lastingly suffer a noticeable loss of competitiveness.

1.3.2 Yard

The starting point for the planning of yard suprastructure is the calculation of yard slots (*i.e.* the number of 20 ft positions) with due regard to the annual quay wall throughput, the dwell times assumed for different container types and the admissible maximum yard utilization (due to operational reasons).

Subsequently, the design of yard layout and specification of yard equipment are carried out within a recursive planning process considering a multitude of requirements on the yard system. The results of preplanning activities usually outline one or more equipment alternatives for yard operations being evaluated by arising investment and operating cost. The operational capabilities and expected cost of each technical alternative finally form the basis for the decision on a particular equipment type.

Within the scope of detailed planning the favored equipment alternative is continuously specified in respect of the requirements to be met by the single elements of yard suprastructure. This applies again to functional requirements (if necessary) and in particular to the elaboration of technical and process-related requirements. Eventually, the results of requirement engineering define the framework and basis for equipment procurement and construction measures or the associated tendering processes, respectively. The main requirements to be considered by yard planning on the suprastructure level are outlined in the following:

- quay wall throughput per year
- quay wall throughput in peaks
- available size and shape of yard area
- container dwell times
- handling performance of quay cranes
- system restrictions relating to max. utilization
- hinterland modal split
- cost restrictions
- technology alternatives to be considered for investigation

- degree of automation

The first contribution within this planning area focuses on the issue of ’yard layout’ and in particular on the design of a container block storage being operated by rail-mounted gantry cranes. The two others highlight algorithms to support the short-term scheduling of yard resources. From the perspective of suprastructure planning, knowledge of related algorithms and their potential impact on yard operations is essential for an adequate evaluation of logistics capabilities and economic viability of yard equipment, considering the respective application environment. Appropriate knowledge in this regard represents an indispensable prerequisite for planning of yard suprastructure meeting the requirements.

Wiese et al discuss the impacts of yard handling technology on the terminal layout and define different layout categories for the yard area. Considering container blocks perpendicularly oriented to quay wall and operated by automated rail-mounted gantry cranes, the authors propose a planning approach to calculate promising block storage configurations. The procedure enables terminal planners to choose a solution for their specific situation including performance and cost aspects. In this context *Wiese et al* also investigate the influence of reefer rack installations and their distribution over container blocks on the yard performance.

The problems studied in the contribution of *Caserta et al* refer to a post-stacking situation, *i.e.* problems arising after the stacking area has already been arranged. In order to increase efficiency of loading/unloading operations, once updated information about the state of the containers, as well as of the vessels becomes available, it is possible to reshuffle the container yard, or a portion thereof, in such a way that future loading operations are carried out with maximal efficiency. Three types of post-stacking problems have been identified and explained thoroughly. With respect to each of these problems, the relevance and connections with other container handling issues are described and algorithmic approaches to tackle such problems are summarized.

The latest trends in container yard operations are different kinds of automated *R*ail-*M*ounted *G*antry (RMG) crane systems. In this regard, the contribution of *Kemme* describes the main characteristics of various yard systems based on RMG technology and gives an extensive overview on algorithmic approaches for RMG crane scheduling and container stacking. Furthermore, the author outlines effects of the use of algorithms for equipment control on suprastructure planning.

1.3.3 Landside & Hinterland

With respect to suprastructure on the terminal landside the main planning objects are the interfaces to the hinterland transport systems, *i.e.* the *truck gate* in conjunction with the truck handling area (or positions), the *railway station* and the *barge terminal*. Seaport container terminals do not necessarily provide interfaces to all transport systems of the hinterland. If a terminal has no hinterland connection enabling domestic container transport, it represents a pure transhipment facility.

Analogous to the other planning areas the tasks of suprastructure planning are constituted on the landside of seaport container terminals and the hinterland. This means that preplanning activities typically end up with a decision on the favored (technical) alternative type and detailed planning additionally performs requirements engineering for the previously chosen alternative and specifies in terms of functional, technical and process-related requirements.

Within the scope of *gate* planning especially the number of truck dispatching lanes, the size of necessary parking and waiting areas as well as the overall arrangement of gate elements on the terminal site must be determined. Additionally, for the un-/loading of trucks an appropriate location and layout of the handling area (positions) are to be chosen and the kind of terminal equipment and the number required for truck handling must be specified. In order to keep the operating costs for the terminal low, planners endeavor to realize the un-/loading of trucks with the equipment considered for yard operations. In this way, no additional horizontal transport is required between the full container yard or empty depot and the truck handling area (positions).

Regarding the design of the *railway station*, among other things, the number of rail tracks, the equipment used for un-/loading of trains and the location / layout have to be investigated. First, for each planning problem the main functional requirements are elaborated enabling the choice of a technical solution regarding its type (preplanning) and afterwards the favored alternative is specified in greater detail (detailed planning). Accordingly, the suprastructure of a *barge terminal* is to be elaborated. Planning also includes activities like requirements engineering for the handling equipment, the design of the barge terminal layout or the analysis of favorable barge terminal location.

Basically, it has to be guaranteed by suprastructure planning that given economic and logistic requirements for the landside interfaces (*i.e.* truck gate, railway station and barge terminal) are met by the technical alternatives specified for problem solution. In this regard, typical requirements for landside operations are the following:

- annual throughput of truck, train, barge containers
- volume of truck, train, barge containers in peak hours
- number of trucks, trains, barges in peak hours
- arrival patterns for hinterland traffic modes
- maximum handling time per vehicle
- changes in modal split
- technical restrictions for access to hinterland transportation systems

In addition to the landside interfaces the *empty container storage* and *internal container transports* (*e.g.* movements between the yard and railway station or barge terminal) also represent relevant tasks of suprastructure planning on the terminal landside. For both terminal functions the use of equipment has to be dimensioned qualitatively and quantitatively. In view of empty container storage, the location, layout and size of an appropriate depot must be determined additionally.

Another important task of suprastructure planning on the terminal landside is the structuring of traffic flows which usually possess a high complexity due to their (different) nature and extent. In this regard, the requirements on horizontal transports arising in other terminal areas (yard and quayside) also must be considered. The objective is to form an effective overall traffic concept that guarantees a smooth traffic flow for typical workload scenarios in all operations areas.

Since the influence of terminal operators on the design of infrastructure for hinterland access is limited (especially in case of bottlenecks) they aim at well (ideally optimal) utilization of existing capacities. From the point of view of suprastructure planning the information and communication technology represents an effective way to support operational processes of the landside interfaces. Inter-organizational IT systems allow a demand-driven provision of information between co-operating companies and so they create the necessary prerequisites (by broadening the information basis) for more economic use of terminal resources. Effects by the use of IT especially apply to operational processes on the landside and in the container yard. In this regard, the main task of suprastructure planning is to specify the ‘right’ requirements for such (inter-organizational) IT systems knowing which technologies come into question and which potential may be exploited by the use of related systems.

The Handbook contributions for the landside planning area deal with issues of the interfaces ‘truck gate’ and ‘railway station’ as well as with the access infrastructure to hinterland traffic networks. The contributions particularly discuss organizational and IT-based measures (i.e. solution approaches) for better use of given structures and outline the possible impact on terminal operations.

Against the background of dominating share of truck transports in the modal split of many seaport container terminals the coping with the vast flow of vehicles and containers becomes a real challenge. A high efficient use of the truck gate suprastructure and organization of truck flow to/from hinterland road network is inevitable prerequisite to provide good customer services or fulfil existing demands, respectively. The contribution of *Geweke and Busse* presents various measures for the terminal itself and the closer hinterland enabling a better utilization of available resources. Additionally, they touch upon the subject of shifting volumes to other modes of transport presenting an example from the port of Rotterdam.

Likewise, focussing on better utilization of landside terminal resources *Huynh and Walton* deal with the application and configuration of a truck appointment system for automated control of in- and outbound container transports by road. Authors investigate different rules for the assignment of trucks to appointment times as well as limitations of the maximal number of truck arrivals permitted for a certain time window. The analysis is carried out by means of discrete event-orientated simulation. Effects of parameters settings chosen for simulation experiments are measured by the yard turn time of trucks and the yard crane utilization.

For actors of logistics transports chains the inter-organizational integration on the informational level usually represents a promising possibility to increase their resource efficiency. Due to higher information availability the quality of planning on the operations level can be improved leading to higher productivities of resources. The paper of *Jürgens et al* presents a case study that reveals the economic potential of advanced data flow for the operation of seaport container terminals. The study is carried out at the Container Terminal Altenwerder (Hamburg) and especially includes the investigation of operational improvements at the railway station and in the container yard.

Considering the *hinterland* of seaport container terminals the influence of operators on infrastructure decisions is basically limited (see Section 1.1). Tasks for suprastructure planning arise, when the terminal operator decides to operate (additional to the seaport terminal) further inland facilities (so-called ‘dry ports’) . For suprastructure planning on the one hand similar problems to a seaport container terminal have to be solved (*e.g.* specification of equipment for un-/loading of transport units) but on the other hand questions of fundamentally different character are to be answered. The latter mainly results from the non-existent connection to sea and the necessity of land-based container transports between the inland terminals and the main terminal as well as from significantly shorter dwell times of container storage. Ideally, the interchange of containers between transportation systems should be directly in inland terminals in order to minimize time losses and operational expenditure as much as possible.

The Handbook contributions for the hinterland planning area particularly discuss solution approaches for enhancing the logistic development of the seaport hinterland. The introduced approaches increase storage and transport capacities and help to overcome bottlenecks (and congestions) in the seaport and its terminals. They additionally improve the competitiveness of the port (terminals) in comparison to other seaports in the region since the catchment area can be systematically expanded and more customer-oriented services become possible. In this respect, also the endeavors of public authorities and political instances are investigated and evaluated which should increase the attractiveness of railway and inland waterway traffic based on an appropriate legislation.

In recent years, the dry port concept has increasingly been applied as a deliberate attempt at expanding or reinforcing the hinterlands of container ports. In this context, the contribution *Cullinane and Wilmsmeier* applies the marketing concept of product life cycle to ports and relates implementation of dry port network to the prolongation of the growth and/or maturity phases of a port’s life cycle. In doing so, the dry port concept is explained by reference to both the literature and industry examples. Finally, the prospect of dry ports exerting a positive impact on the life cycle of container ports is evaluated.

In view of increasing volume requirements in the international container traffic the handling capacities of seaport container terminals as central nodes within an intermodal network of transportation systems represent one important aspect. Another important role for overall network performance play the in- and outbound container flows from and to deep sea or hinterland, respectively. Focussing on bottlenecks in transport capacity in the hinterland of seaport container terminals the contribution of *Daduna* presents innovative logistics concepts to solve existing problems partly in conjunction with functional descriptions for concept implementation.

The contribution of *Shinas and Dionelis* focus on the problem that today cargoes frequently leave European seaport terminals by road despite strong political support and countless measures of public bodies in the past. The contribution presents a thorough examination of European policy developments in the fields of rail, inland waterways and intermodality including also environmental issues. The data from EUROSTAT is used as a basis for further analysis, revealing the today's market situation of the aforementioned transport options. Moreover, an estimate is given regarding the further development and the expected success of promotion measures in future. As possible solution approach the concept of dry ports and its function in the canalization of cargoes is investigated in view of sea-rail and sea-river links.

1.4 Challenges of Terminal Planning

In the past years and decades the work of actors involved in the suprastructure planning of seaport container terminals was affected by the requirements of a steady growth market for more capacity. Due to (comparatively) reliable traffic forecasts associated with well-calculable resource utilization the challenges to provide terminal capacities at competitive cost were limited. Suprastructure planning tasks in the scope of facility expansion, technology conversion of terminals in operation or 'greenfield' projects were in the center of attention. Furthermore, planning activities in industrialized high-wage countries were (and are) usually accompanied by considerations for the automation of single or several operations areas in order to decouple operational activities as far as possible from the comparatively high labor costs and so create durable competitive advantages.

Various global trends in international container traffic (such as the growth of vessel size on the intercontinental round trips of container shipping, or the steady increase of handling capacity in many ports) have resulted in significantly more competition in the recent past, particularly between the seaport container terminals in regions with high terminal density. A dramatic acceleration of this development was the result of the global financial crisis in 2008.

World's growing environmental problems and stricter legal provisions concerning the protection of the environment have led to the fact that also for companies of the container transport and handling industry the environmental aspects of their operational activities play an important role in the meantime. To have long-term success as a terminal operator, existing environmental guidelines and emerging legislative changes have to be included systematically into management decisions and operational processes must be (anticipative) aligned to such regulations based on their environmental impacts.

Against the background of the outlined changes the requirements for the suprastructure of container terminals are shifting and thus also the range of planning tasks on the suprastructure level. The challenges of suprastructure planning in future will be to create the necessary conditions for terminal operation that allows successful realization of (highly) conflicting objectives in partially different dimensions. So in a comparatively tough competition for terminal operators it will depend especially on implementing objectives in the areas of

- cost efficiency,

- dealing with exceptional peak load situations in all terminal areas,
- limitation of environmental impact, and
- systematic logistic development of the terminal hinterland

at a high level in order to cope with market requirements on a long-term basis. Promising ways to identify good solutions for multi-criteria problems in system planning may result from the concepts of integrated and anticipative planning (see, *e.g.* Rahim and Ben-Daya (2001) and van Wezel et al (2006)) or the use of life cycle costing approaches (see, *e.g.* Flanagan (1989)). Instrumental support can be delivered by modeling techniques enabling a flexible representation of real world aspects in terms of complexity, stochastics and dynamics according to the requirements of the modeler or the application case, respectively (see Section 1.2).

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Part II
Basic Aspects: Technologies & Instruments

Chapter 2
Operations Systems of Container Terminals: A Compendious Overview

Birgitt Brinkmann

Abstract
This section contains an overview of the different functional areas of a marine container terminal and a summary of the main types of container handling systems. The main advantages and disadvantages of each type of handling system are also summarized without focusing on technical details.

2.1 Functional Areas of Terminal Operations

As every other terminal, a container terminal is a complex system that functions only efficiently when its layout is designed in such a way that the loading and discharging process of vessels runs smoothly. A container terminal consists of at least three operational areas:

1. operational area between quay wall and container yard (apron or the area just behind the berth front)
2. container yard (terminal storage = stacking area)
3. terminal area of landside operations (including the gate, parking, office buildings, customs facilities, container freight station with an area for stuffing and stripping, empty container storage, container maintenance and repair area etc.)

The importance of the container freight station has decreased within the past decades as more and more containers are sent directly from the originator to the addressee without being transhipped. Nevertheless, a lot of terminals are provided with a container freight station for storage purposes. Figure 2.1 shows the schematic layout of

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a container terminal with the different operational areas. The transport between the areas is carried out using handling equipment for horizontal container transport. The layout and choice of equipment for the above mentioned areas and their interfaces depend on, amongst others, the

- number of containers to be handled,
- available area and
- mode of hinterland transport.

The combination of terminal equipment used

- at the vessel,
- for transport tasks between quay and stacking yard (or vice versa),
- for container stacking,
- for transport from stacking yard to and from the landside operation area and
- for landside operation itself

is called operations system.

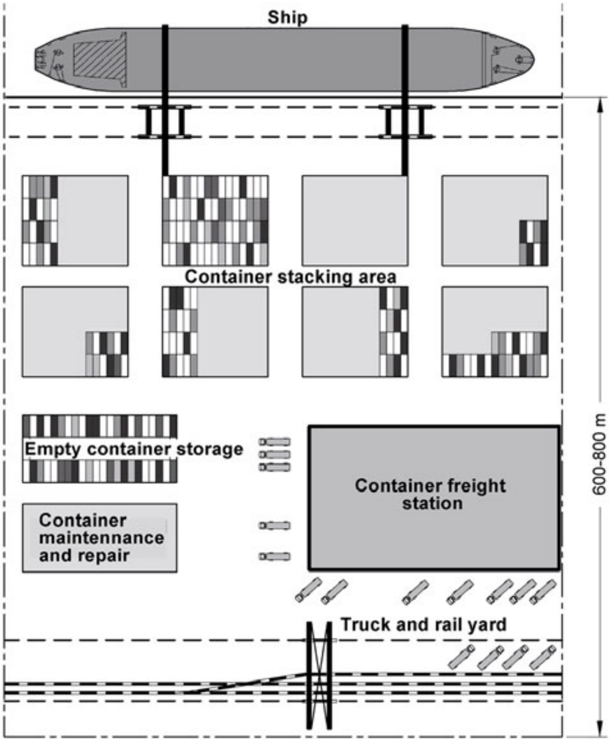

Fig. 2.1 General layout of a container terminal (see Brinkmann (2005))

Independent from the selected terminal operations system, specific processes are performed on the different areas.

On the apron area the ship-to-shore operations (loading and discharging of vessels) are carried out. In the beginning of the container shipping the cargo handling on this area was mainly carried out with on-board lifting gear of the vessels or a regular quay crane. Nowadays this type of handling is only used on terminals with a comparatively low container throughput. On medium and large sized terminals the ship-to-shore handling of containers is usually carried out with gantry cranes specialized in this purpose.

Container vessels are the only ships that can be loaded and discharged at the same time. The *S*hip-*T*o-*S*hore gantry crane (so-called “STS crane”) discharges a container moving landwards and on its way back loads a container on to the vessel. This handling procedure requires good planning of the terminal equipment for the container delivery as well as for the container stacking in the yard and on the vessel. Landwards, the full container yard borders on the apron, used for

- storing inbound (discharged from vessels) and outbound (to be loaded on vessels) container as well as for
- storing export containers delivered by train or truck, and forwarding import container to these modes of transport.

These operations usually do not happen at the same time. Therefore, the container yard is an intermediate storage facility, in which the containers remain from a couple of hours to some weeks (container dwell time = containers in the same position or area during this period of time, *e.g.* within the terminal area). There are different possibilities for the layout of this intermediate storage area (= stacking yard). If the stacking area is a compact, low ground area consuming stack without spacing, it is called block stack (see Figure 2.2; HHLA (2010)). In this case, yard gantry cranes are used for the stacking of containers being delivered by terminal equipment of horizontal transport. An alternative is the linear stack (see Figure 2.3) where the containers are stacked by *S*traddle *C*arriers (SC). This type of stacking requires spacing between the container rows and relatively wide terminal roads. Export and import containers are segregated within the yard area), piled up to 4 containers high and (relating to import boxes) pre-sorted for the different hinterland transport modes. The third rarely applied stacking alternative is the high-bay racking, used for terminals with high throughput requirements but very small available area. An example is Hong Kong with high-bay racks up to 12 container tiers.

The configuration of the area for landside operation, as third main functional area of container terminals, is determined by the hinterland transport modes or related interfaces, respectively. In case of predominant truck operations, this functional area is often integrated in the yard area. The trucks are loaded and unloaded on dedicated spaces at the end of the stacking yard or in the middle of the yard, *e.g.* by SCs or yard cranes. In case of railway transport the loading/unloading should take place outside the stacking area to avoid the crossing of rail tracks by the yard equipment. This would increase the terminal efficiency and performance as well as the safety on the terminal. The loading/unloading is carried out directly by the yard equipment or by gantry cranes being combined with appropriate vehicles for horizontal transport between railway station and terminal yard.

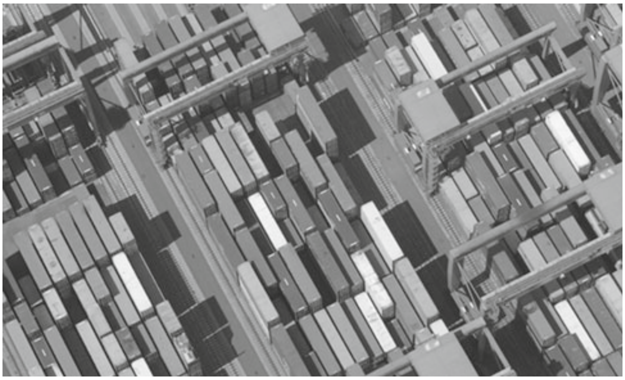

Fig. 2.2 Block stacking

Fig. 2.3 Linear stacking

As only a traveling vessel makes money, the berthing time at the terminal quay wall should be as short as possible. First and foremost this can be achieved by a fast loading / discharging process of the vessel. To ensure this, the operational areas have to be tuned to each other.

The length of a container terminal depends on the planned number of berths and the length of the design vessel as well as local restrictions (*e.g.* given geographic conditions). The (minimum) depth of the terminal depends on the operations system. The available area is a crucial factor for its selection. As a guide value, 600m–800m should be appropriate for new constructions of terminals.

The remainder of this paper is organized as follows. Section 2.2.1 provides a brief overview of common equipment types and meaningful factors for equipment choice. In Section 2.2.2 to 2.2.5, various operations systems are introduced regarding their use of handling equipment for container stacking and transport in the operational terminal areas mentioned above. Additionally, the main operational and economic advantages and disadvantages are outlined system-related. Lastly, Section 2.3 concludes the paper with an overview of functional system capabilities.

2.2 Operations Systems

2.2.1 Determinants of Operations System Choice

To design and operate a successful container terminal is a challenging task with the objective to decrease the cost of operation while at the same time service quality and effectiveness of operation have to be increased. The new large container terminals being under construction, the ones already being designed and the future ones are ambitious projects (due to complexity and given economic/capacity requirements) and will challenge the terminal operators to further increase the efficiency and/or performance of loading/discharging processes. To achieve this, not only larger and faster STS cranes are required but also logistic capabilities of horizontal transport equipment to cope with augmentation of STS cranes. Therefore, the right selection of the operations system is a key factor to a successful terminal. The decision for an operations system depends, inter alia, on the following factors:

- size of vessels
- traffic forecast (annual container volume)
- container volume in peak hours
- available land area
- required stacking density of the containers per ha (configuration of stacking yard)
- cost structure (wages, financial facilities, dues)
- aimed STS productivity (*i.e.* TEU / crane / hour)
- geographic restrictions of the terminal area
- contingent restrictions due to soil conditions
- environmental impacts like wind, ice, noise, light and snow
- mean dwell time of containers in the stacking yard
- TEU factor (*e.g.* 1,6 implies 60% of all containers are 40 ft long)
- percentage of reefer containers
- percentage of empty containers (short: MTs)
- percentage of LCL (*L*ess than *C*ontainer *L*oad)
- the connections to the hinterland transport modes road, railway and inland waterways

The number of determinants shows that there is no “general ideal” container terminal. The usual equipment to fulfil the tasks in the three mentioned functional terminal areas (see Section 2.1) are:

- quay cranes at the vessel:
  - STS crane

  - conventional quay crane
  - mobile harbor crane

- for container transfer (horizontal transport):
  - SC (max. stacking capability: 1-over-3-high)
  - reachstacker
  - terminal tractor with trailer (so-called *T*ractor-*T*railer *U*nit (TTU))
  - multi-trailer (terminal tractors with several trailers)
  - empty/loaded container handler
  - *Sh*uttle *C*arrier (ShC stacking capability: 1-over-1-high)
  - *A*utomated *G*uided *V*ehicles (AGV)
  - automated SC (max. stacking capability: 1-over-2-high)
- for container transport and stacking within the yard:
  - SC
  - *R*ubber-*T*yred *G*antry crane (RTG crane)
  - *R*ail-*M*ounted *G*antry crane (RMG crane)
  - container handler (like reachstacker or top lifter)
  - *O*ver*H*ead *B*ridge crane (OHB crane)
- for the landside operation:
  - SC
  - RTG crane
  - RMG crane
  - reachstacker
  - TTU
- at the inland navigation vessel:
  - STS crane
  - conventional quay crane
  - mobile harbor crane

Considering the fact that the above-mentioned equipment is available in different sizes and special designs (*e.g.* one or two trolley STS cranes, SCs for 3- or 4-high stacking (*i.e.* 1-over-2- or 1-over-3-high), yard cranes of different heights and widths, reachstackers with different lifting heights and loading capacities) and the possibilities of various combinations, it is obvious that special care has to be paid to the analysis and choice of the "optimal" operations system comprising the qualitative (kind of equipment) and quantitative (number of equipment) dimensioning of system resources.

Notwithstanding the mentioned variety there are some commonly used systems being explained below with their main pros and cons listed briefly. Representing possible types of quay cranes only the most efficient one, the STS crane, is being considered. Due to operational and economic restrictions not all types of horizontal and vertical transport equipment can (or should) be combined.

Because of the diversities of equipment types, the choice of the operations system results in considerable different terminal layouts.

2.2.2 Reachstacker System with Tractor-Trailer Units

The STS crane drops down containers on TTU that transport the containers to the stacking area (see Pirhonen (Chapter 3 of this Handbook)) where the boxes are stacked by reachstackers (see Figure 2.4) or forklift trucks fitted with appropriate spreader frames for container top or side lifting. Traditionally heavy fork lifts were used but nowadays most operators use reachstackers because of their higher operational productivity and flexibility enabling a higher stacking density as well.

- due to their versatility in operation, reachstackers are often the best choice for small and medium size container terminals and for multi-purpose terminals. As they are easy to handle reachstackers in particular are a good choice for countries with little trained labor.
- reachstackers can be used for stacking in the yard, loading and unloading of TTUs, road trucks and rail cars on first rail.
- TTUs are used for the transport of the containers between the vessel and the container yard.
- reachstackers can also be used for short distance transportation, so that no additional equipment is required on small terminals.

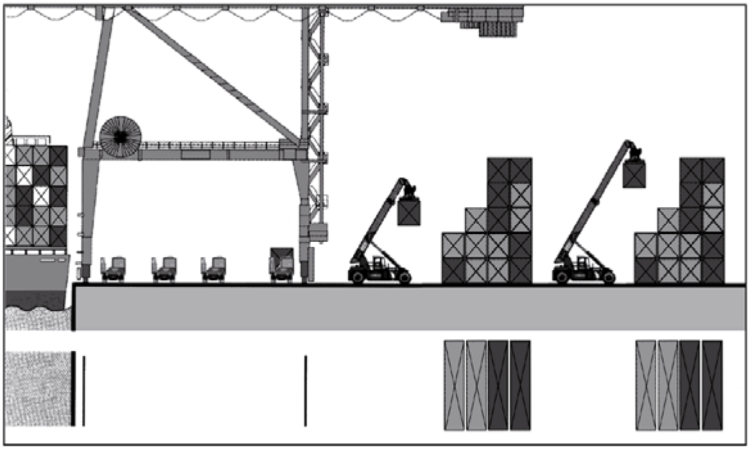

Fig. 2.4 Stacking example of operations system with reachstackers and TTUs (see Kalmar Industries (2010))

- including landside operation, an estimate of 3–4 reachstackers and 4–5 TTUs are required per STS crane (rough rule of thumb of operations practitioners noticing that *e.g.* the specific number of TTUs in particular depends on the distance between the berth and the stacking area of the respective application case).

- a storage capacity of approx. 350 TEU per hectare for 3-high stacking and 500 TEU per hectare for 4-high stacking are common figures for this type of yard equipment. The maximum stacking height is 5, container blocks can be kept 4-deep due to second row access. Among others, another stacking possibility is a depth of 8 when stacked in pyramid shape. To avoid too much reshuffling of the stack, the stacking is often limited to 2 deep and 3–4-high.
- in case of relocation of capacities reachstackers could be easily transported to another terminal or used for other cargo handling. Because of their easy transportation between terminals (or terminal areas) reachstackers could be used to cover temporary peak requirements.

System advantages

- low investment and capital costs as reachstackers and TTUs cause relatively low purchase expenses per equipment unit
- low operating costs of equipment in comparison to other operations system alternatives (prerequisite: low-wage country)

System disadvantages

- container transports between STS crane and yard area require two handover procedures due to the use of different terminal equipment for transport and stacking tasks
- comparatively high manning requirements due to the large number of vehicles and low level of automation, and therefore the impact of labor or operating cost respectively is considerable in high-wage countries
- the TTUs can not pick up or set down the containers self-acting
- disturbance of operation by trucks being loaded/unloaded in the stacking area

2.2.3 Straddle Carrier System

The STS crane places the containers onto the apron from where the SCs transport them to the stacking yard (see Figure 2.5 and Figure 2.6) and stack the containers. The SCs are independent from any other equipment and are able to perform all the different handling operations: transport, stacking and the loading/unloading of trucks and rail cars (see Figure 2.6b).

- SC systems are often the optimal system for medium and large size terminals, when high flexibility in the yard and accessibility of the boxes are required. Within this system it is easy to alter the layout of the terminal.
- due to the required traffic lanes the system allows only a medium stacking density. Based on practical experience a storage capacity of approx. 500 TEU per hectare stacking 2-high (3-high SC) and 750 TEU per hectare stacking 3-high (4-high SC) can be achieved. The maximum stacking height is 4-high.

- including landside operation, an estimate of 4–5 SCs are required per STS crane – without considering specific conditions.
- on some terminals the system is supported by container handlers stacking MT boxes and/or RMGs for container handling in the rail yard.

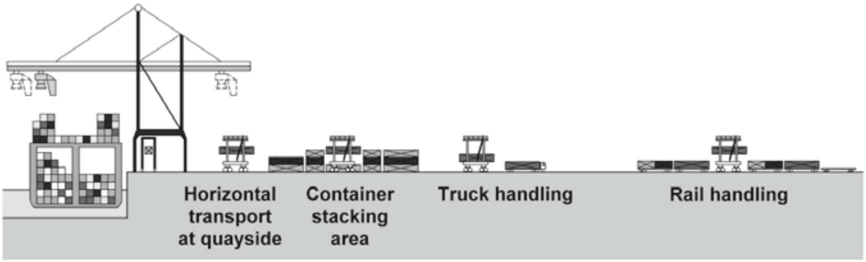

Fig. 2.5 Pure SC system

System advantages

- SC are able to cover all kinds of horizontal and vertical transports being necessary to perform container moves from the landside terminal interfaces (including truck handling and rail operation) via the container yard to handover positions below the STS cranes at quayside (and vice versa). Thus, pure SC operations systems (not considering the STS cranes) are viable and combinations with other (compatible) equipment types are facultative only or are induced by particular logistics or economical requirements, respectively
- the containers can be dropped on the ground so that no (or only short) waiting times for handling equipment occur. This kind of container handover enables STS cranes to operate with a high productivity while using a comparatively low number of SCs per crane.
- high number of concurrent container movements
- the breakdown of one SC has a comparatively low impact on the total handling process
- compared to the systems with TTUs the labor costs are lower due to the smaller number of vehicles
- no disturbance of the operation by trucks because these are loaded/unloaded outside the stacking yard
- the system is flexible to changes based on operational requirements and terminal layouts can be simply altered as SCs can be easily moved within the terminal since no pre-set routes or tracks are needed

System disadvantages

- high investment and capital costs for the SCs

- high maintenance and energy costs
- high labor costs compared to (semi-)automated transport and stacking systems (see Section 2.2.5)
- high area requirement in comparison to yard cranes as a result of a lower stacking height and a large proportion of traffic (within the yard area)
- when traveling distances are far, SCs are not the first choice as they are considerably slower compared to TTUs and more costly

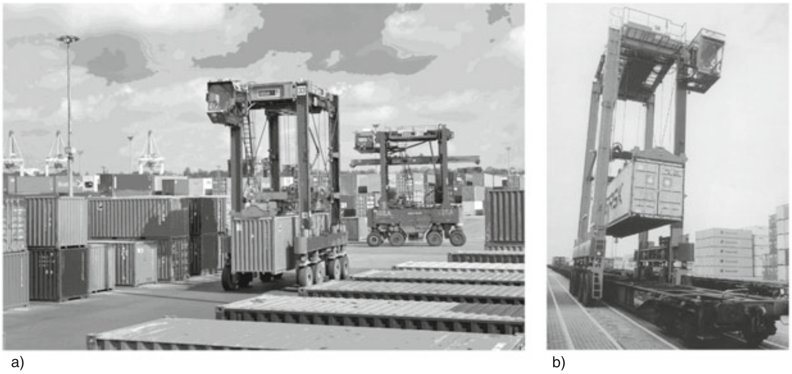

Fig. 2.6 SC operation: a) Container transport and stacking; b) Loading / unloading of rail cars

2.2.4 Rubber-Tyred Gantry Crane System with Tractor-Trailer Units

The STS gantry crane places the container on a TTU unit that transports the container to the storage area where the RTG crane stacks the containers in long blocks (see Figure 2.7). A RTG can be used for TTUs and road trucks as well. The size and structure of the RTG crane is determined according to the requirements of the terminal operator.

Very heavy concrete paving is required in the wheel tracking areas to support the heavy wheel loads. Besides, there are concrete/steel pads necessary for turning purposes of the cranes to travel to adjacent storage areas (or blocks) to perform stacking operations. RTGs are generally smaller and lighter than RMGs (see Section 2.2.5). Therefore, they are sometimes to be favored for terminals built on reclaimed marshland, where reinforced piling would be too costly.

- RTG cranes are often used on large and very large terminals. The system has a very high stacking density because of the high stacking capability and the block

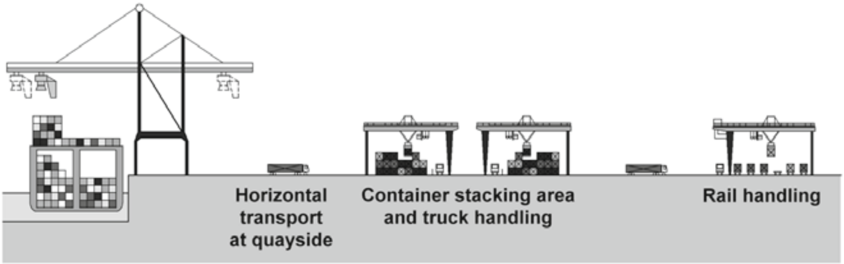

Fig. 2.7 *R*ubber *T*yred *G*antry (RTG) cranes and TTUs in the stacking yard, rail yard operation by RMGs

stacking. Long traveling distances on the terminal are less problematic as TTUs transport the containers

- RTG cranes can also be effectively used for the handling of containers on road trucks or rail cars. According to manufacturers, up to four tracks can be covered and containers can be stored at the side of the rail tracks
- RTG cranes can be allocated from the yard to the landside operation and vice versa, if necessary
- including landside operation 2–3 RTGs and 4–5 TTUss (depending on the distance between berth and stacking area) are required per STS crane (rule of thumb based on practical experience)
- RTGs stack the container in blocks 1-over-4- to -7-high and 5 to 8 container rows plus 1 lane for container handover lane
- as a rule of thumb based on practical experience, the capacity of the yard is approx. 1,000 TEU per hectare (stacking 4-high)

System advantages

- low space requirement in the stacking area because of the high storage capacity in a small area (high stacking density). The containers can be stacked up to 8-high (*i.e.* 1-over-7-high)[1] without spacing for traveling lanes between the rows. To avoid reshuffling of the containers, an efficient administration of the yard is required.
- relatively high flexibility as the RTGs can be transported to other storage blocks
- medium investment capital costs per piece of equipment

System disadvantages

- container transports between STS crane and yard area require two handover procedures due to the use of different terminal equipment for transport and stacking tasks

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[1] Common RTG systems offer nowadays max. stacking capability of 1-over-6-high, but systems with seven tier stacks for container storage are available.

- disturbance of TTU operations by trucks being also loaded/unloaded in the stacking area (mixed traffic)

2.2.5 Rail-Mounted Gantry Crane System

2.2.5.1 Rail-Mounted Gantry Crane System with Tractor-Trailer Units (blocks parallel to quay)

The system generally complies with the RTG system, but the cranes are mounted on fixed rail tracks with a cantilever outside the portal of cranes (see Figure 2.8).

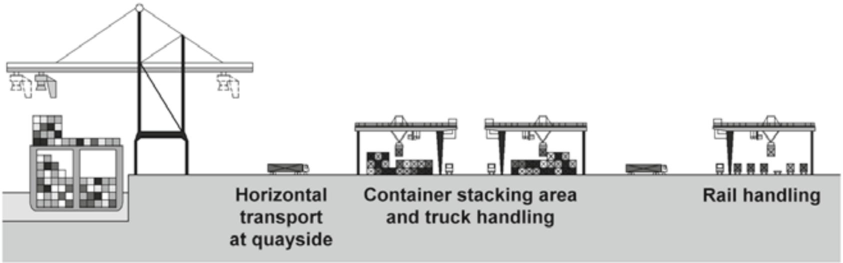

Fig. 2.8 RMG cranes with TTUs

System advantages (compared to RTGs)

- RMGs generally stack higher and span wider, with up to 1-over-7-high and 12 containers wide
- based on practical experience stacking density of the yard is higher with RMG cranes and can exceed 1,000 TEU per hectare (stacking 4-high)
- more durable and reliable than RTGs
- higher availability with moderate maintenance and repair costs
- Medium operating costs because of relatively low maintenance costs
- Easier to automate than RTGs

System disadvantages (compared to RTGs)

- more expensive to install because of required tracks
- high disturbance of terminal operation in case of crane failure
- high investment and capital costs due to equipment and construction costs (rail tracks) in comparison to other types of block stacking systems
- rigid system in operation because of rail mountings and more difficult to change the layout in the yard

2.2.5.2 Rail-Mounted Gantry Crane System with Automated Guided Vehicles or Shuttle Carriers (blocks perpendicular to quay)

The horizontal transport of the containers is performed with AGVs (see Rijsenbrij and Wieschemann (Chapter 4 of this Handbook)) or ShCs (see Pirhonen (Chapter 3 of this Handbook)). For safety and operational reasons, the automation requires a strict separation between the AGV area and the area with manned equipment (see Figure 2.9).

Hence, the handover positions for trucks are located at the top-end of the stacking blocks. The stacking of the containers is usually carried out by automated RMGs. The ShC is designed primarily to convey containers between the ship's side (due to stacking capability of only 1-over-1-high machines are considerably smaller than conventional SC and therefore more manoeuvrable) and container stacks served by RMG cranes. As it is able to stack containers two high it can also be used for loading and unloading road trucks and rail cars. The shuttle carrier is an alternative for terminals that aim at more efficiency to handle the container transport between the stacks and the quay cranes, and still maintain high density stacking by RTG or RMG yard cranes.

System advantages

- very low labor costs because of automation
- high system availability
- very high productivity of horizontal transport

System disadvantages

- very high investment and capital costs
- very well trained labor required
- rigid system

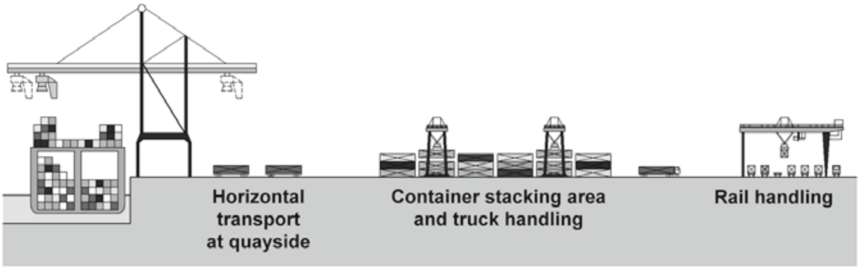

Fig. 2.9 RMG cranes with AGVs

2.3 Summary of Main Data

The data summarized in Table 2.1 is based on practical experience and averaged from a multitude of terminals operated in different countries around the world and does not include allowances for maintenance and repair.

The data should be used only as rule of thumb for plausibility checks and must not be used for planning a container terminal (*e.g.* required area and number of handling equipment) as each terminal is different and the boundary conditions like area layout, operational requirements, legal restrictions etc. vary from location to location. Therefore, the design of each container terminal requires an individual solution.

Table 2.1 Main data of operations systems

Operations System	Required equipment per Quay Crane$^{(2+3)}$	Stacking Tiers [1-over-*n*-high]	Yard Capacity [TEU / ha]
Reachstacker & TTU	3–4 Reachstackers + 4–5 TTUs	3	350
		4	500
		5	950–1,000[4]
Pure SC	4–5	2	500
		3	750
RTG & TTU	2–3 RTGs 4–5 TTUs	4–5[5]	1,000
RMG & TTU (blocks parallel to quay)	2 RMGs 4–5 TTUs	4–5	1,000[6] (or more)
RMG & ShC (blocks perpendicular to quay)	2 RMGs 2–3 ShCs	4–5	1,000[6] (or more)
RMG & AGV	5–6	4–5	1,000[6] (or more)

[2] Generally, the number of equipment per STS crane depends on the distance between stacking yard and berth, the productivity of the STS crane, the locations of the containers within the yard, the quality of stacking in regard to export containers (sorting with respect to destination ports and weight classes), the interaction between vessel stowage planning and yard planning.

[3] The required number of equipment refers only to the horizontal transport between berth (STS cranes) and stacking yard and should be considered more differentiated, particularly with respect to RTGs and RMGs which in a lot of cases also handle the delivered export containers as well as import containers to be loaded on road trucks and additionally carry out reshuffling of containers in the yard.

[4] Only empty containers.

[5] Max. 1-over-7-high (high costs for reshuffling of containers which decreases the productivity and increases the number of required RTGs).

[6] Independent from space requirements of horizontal transport equipment.

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Chapter 3
Automated Shuttle Carrier® Concept
Comparison to Conventional RTG Crane and Yard Tractor Concept

Jari Pirhonen

Abstract
The paper deals with innovative handling technologies of container terminals enabling the automation of transport and storage processes at terminal quayside and within the yard area. The presented shuttle carrier concept is based on the employment of Automated Shuttle Carriers® in combination with rail mounted stacking cranes, automatically operating storage blocks, arranged perpendicular to the quay wall. Beside a scenario-based investigation of system performance, by means of simulation, the shuttle carrier concept is compared with a conventional handling system using yard tractors for container transport and rubber-tyred gantry cranes for yard operation. The system comparison delivers results in terms of equipment and manning requirements as well as insights into the environmental impact of system operation, considering also rubber-tyred gantry cranes powered by electric energy.

3.1 Introduction

The Automated Shuttle Carrier® concept was developed by Kalmar as a result of major port operators looking for solutions, which could combine high vessel productivity, high storage capacity and low overall cost in high labor cost areas. The operations concept couples Automated Shuttle Carriers® (or short ‘Auto Shuttles’) and *A*utomatic *S*tacking *C*ranes (ASCs) for container transport in a highly efficient manner. The former are primarily used for horizontal transport of boxes between the quay wall and the terminal yard, the latter cover horizontal and vertical transport tasks in the container yard itself. Besides operational and economic advantages, the Automated Shuttle Carrier® concept also gives clearly lower environmental impact,

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than conventional handling systems such as *R*ubber-*T*yred *G*antry (RTG) cranes, in combination with yard tractors.[1] Basically, the paper is organized as follows:

The Automated Shuttle Carrier® concept is described in Section 3.2, followed by an introduction to the conventional RTG crane and yard tractor operation in Section 3.3. In the fourth section the main input information and results of operational simulation are shown for the Automated Shuttle Carriers® alternative. The simulation environment Port Optimizer®[2] has been used for this purpose.

In the fifth section a terminal level comparison has been made between the Automated Shuttle Carrier® concept and the RTG crane alternative. The required number of Automated Shuttle Carriers® is based on the introduced simulation results, whereas the figures of all other equipment is based on Kalmar's own database and feedback from customers. A theoretical terminal scenario, focusing quayside operation, forms the framework for this investigation. The scenario includes a certain number of *S*hip-*T*o-*S*hore (STS) cranes with common handling characteristics, noticing that the STSs are to be smoothly served by the operations system.

In the sixth section, comparison of environmental impacts has been made between the system alternatives previously discussed, *i.e.* Automated Shuttle Carriers® combined with ASCs on the one hand, and RTG cranes with yard tractors on the other. The seventh section includes the conclusions.

3.2 Automated Shuttle Carrier® Operations

Automated Shuttle Carrier® concept was developed by Kalmar as a result of major port operators searching for solutions, which could combine high vessel productivity, high storage capacity and low overall cost in high labor cost countries. Automated Shuttle Carriers® are used in the quayside for transportation of containers (see Annala (2007)).

3.2.1 Operations Concept

Automated Shuttle Carriers® work together with ASCs and they are used for transporting containers on the quayside (see Figure 3.1a). Containers are picked up and are landed directly on ground, which makes it possible to decouple vessel and yard operations, thus drastically reducing the waiting times. Usually operations take place under the back reach of the STS cranes, which makes it easier to separate automated and manual areas from one another. A buffer area is used in front of each stack

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[1] Yard tractors are also termed as "terminal tractors" in the specialist literature. Mentioning the trailer for container transport they are also known as "tractor-trailer units" or "tractor-chassis system", respectively.

[2] Proprietary development of Kalmar.

as an interchange zone between the ASC and Automated Shuttle Carriers® (see Anonymous (2008), p. 3ff.).

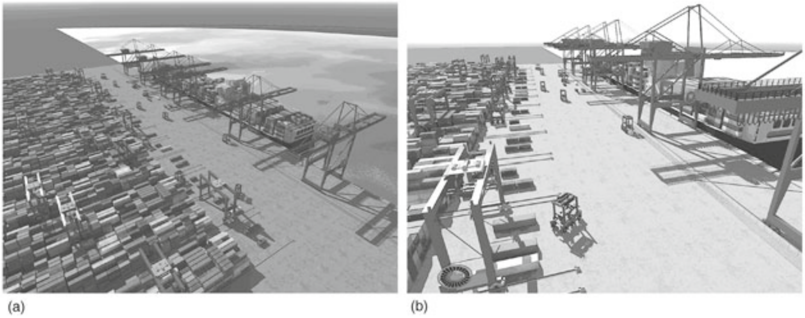

Fig. 3.1 (a) ASC layout at quayside, (b) Automated Shuttle Carriers® transporting containers between ASC and backreach of STS cranes (conceptual 3D models)

3.2.2 Automatic Stacking Cranes

ASCs are used for stacking and transporting containers within the stack (see Figure 3.2a, HHLA (2010)), picking up and landing containers in the quayside buffer area and for loading and unloading road trucks at the landside end of yard stacks. ASCs considered for the Automated Shuttle Carrier® concept belong to the type of rail-mounted gantry cranes. In comparison to other yard crane technologies, ASCs mounted on rail tracks can travel with a container with fast gantry speeds (over 200m per min), *i.e.* they additionally enable efficient container transport within the yard or stacks, respectively.

ASC stacks are usually perpendicular to the quay, mainly to minimize traveling distances and easy separation of quay- and landside operations. A necessary prerequisite to consider for this kind of yard layout is a (sufficient) capability for horizontal container transport. ASC functions are fully automated, except for the loading and unloading of road trucks which takes place via remote control in the rear end of each stack.

There are two main configurations of ASCs:

- two cranes per stack on the same rails (see Figure 3.3a) and
- two or three cranes per stack on separate rails, thus allowing the capability to pass (see Figure 3.3b)

The first alternative gives lower crane and civil engineering costs and higher storage capacity, due to the lower number of rails required. The second alternative gives higher operational flexibility, as large cranes can pass smaller cranes and vice versa; therefore either one can be used both in quay- and landside.

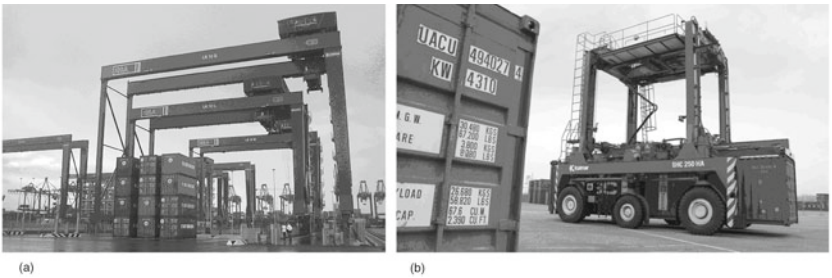

Fig. 3.2 a) ASC at HHLA Container Terminal Burchardkai, Hamburg (Germany), b) Automated Shuttle Carrier®

Based on knowledge of completed, ongoing and planned customer projects, main dimensions for an ASC are usually: 7–10 wide blocks, 1-over-5-high stacking and 36–60 TEU long blocks. The quayside buffer area used with Automated Shuttle Carriers® is usually 2–4 TEU deep and has 3–4 rows depending on the stack width.

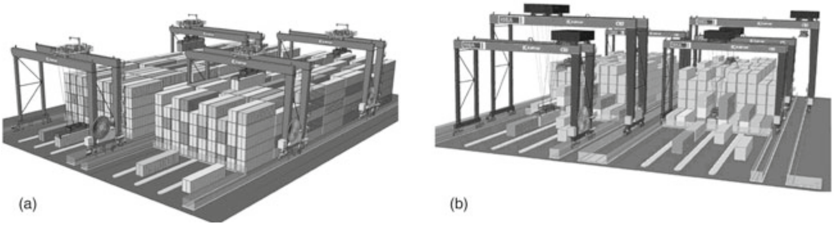

Fig. 3.3 a) ASC with two cranes per stack on same rails, b) ASC with three cranes per stack on separate rails (either conceptual 3D models)

3.2.3 Automated Shuttle Carriers®

Automated Shuttle Carriers® are used for transporting containers between the STS cranes and ASC buffer areas in front of the stacks (see Figures 3.1b and 3.2b). The reason for this is to provide easy interface without traffic congestion, and to minimize traveling distances for Automated Shuttle Carriers®.

Automated Shuttle Carriers® usually have 1-over-1 stacking capability, which enables Auto Shuttles to pass a container on ground while carrying another one. This handling function is important when working on the ASC buffer. Automated Shuttle Carriers® can also handle twin-lift moves. They are controlled by a dispatching and traffic management system (called Terminal Logistics System), which takes care of task allocation, including equipment selection and routing.

3.2.4 Operational Benefits

Automated Shuttle Carrier® concept has clear advantages, in comparison to the conventional RTGs and yard tractor system. The main advantages are seen in the areas of overall cost (in high labor cost countries), vessel productivity, and environmental issues.

Picking up and landing containers on the ground effectively decouples vessel and yard operations, which minimizes waiting times for STS and yard cranes, as they do not need to wait for the transport equipment. Due to the low number of transport vehicles necessary, traffic jams are reduced, especially in terminals handling large vessels with many STS cranes used on each vessel. Also terminals aiming for higher productivity and terminals using twin-lift and dual hoist cranes will gain from the concept of Automated Shuttle Carriers®.

Automated Shuttle Carrier® operation uses equipment pooling, *i.e.* transport vehicles can be freely assigned to any task, which helps to maximize equipment utilization and to reduce average traveling distances. Based on simulation results and knowledge of customer projects, the Automated Shuttle Carrier® concept requires less than 50% of the transport equipment when compared to more conventional transport vehicles, such as yard tractors or *A*utomated*G*uided *V*ehicles (AGV) in automated operation. The Automated Shuttle Carrier® concept makes it possible to reach high STS crane productivity while employing a comparatively low number of transport vehicles. This new concept also gives high storage capacity (due to high stacking and no necessity of traffic lanes for transport vehicles within the yard area) and reduces the requirement for waiting areas at the quayside.

Simulation program Port Optimizer® has been used to demonstrate the gains in efficiency and productivity (also see Section 3.4), when compared to conventional handling technologies. Port Optimizer® is a flexible simulation tool, where any type of container handling system can be simulated. The Automated Shuttle Carrier® concept also offers significant environmental benefits that have also been analyzed (also see Section 3.6).

3.3 Rubber-Tyred Gantry Crane and Yard Tractor Operation

RTG cranes and yard tractors are widely used today in medium- and large-sized terminals. RTG cranes are used in the container yard for stacking as well as loading and unloading yard tractors and road trucks.

3.3.1 Operations Concept

RTG cranes work together with yard tractors on the quayside. Containers are picked up and landed on chassis, which means that yard tractors can easily have waiting times of 50% or more of the total work cycle. Depending on the deployment strategy of tractors they can serve either several STSs or are dedicated to a specific crane at the quay wall. Usually operations take place under the portal of the STS cranes, whereas the backreach area is used for storing of hatchcovers. Twist-lock handling usually takes place while containers are on the trailer, with open corner trailers used. A driving lane is used in each stack for loading and unloading of yard tractors and road trucks, *i.e.* horizontal transport equipment has to travel into the stack to the assigned bay for container handover. Due to operations mode internal and external terminal traffic is usually not separated from one another with this kind of yard crane technology.

3.3.2 Rubber-Tyred Gantry Cranes

RTG cranes are used for stacking containers and for loading and unloading yard tractors and road trucks in the driving lane (see Figure 3.4a). RTG cranes are fairly slow (100m per min) and not designed to carry a container while traveling. RTG stacks are normally arranged parallel to the quay, which is mainly to eliminate disturbances by road trucks on the quayside.

Fig. 3.4 a) Diesel electric RTG crane, b) Yard tractor with trailer – container handover in an RTG block

RTG cranes are manually operated. Semi-automation can be used for example in automatic steering and container positioning. Furthermore, the undercarriage of RTG cranes is mounted on pivoted rubber tyres so that RTGs are able to traverse between different yard stacks (if necessary). This crane characteristic results in a high operational flexibility, enabling RTGs to cope comparatively well with outstanding handling requirements of quayside and/or landside terminal interfaces.

Main dimensions for a RTG are usually: 6–9 containers wide blocks plus driving lane, 1-over-5- or 1-over-6-high stacking and 40–50 TEU long blocks. The driving lane is usually 4–5 m wide. Most of the RTGs in operation are diesel electric cranes. Zero emission RTG cranes are becoming more popular (see Figures 3.5a and 3.5b). The very first units were delivered to Port of Oslo in Norway in 2002 by Kalmar.

Zero emission RTG cranes are designed without a diesel engine and instead are powered via an electric cable. This allows all accumulated energy to be reused, vastly improving energy efficiency. In comparison to conventional RTG machines, the use of this type leads to a noteworthy decrease in energy consumption. Zero emission RTG energy costs are roughly 20% of diesel electric RTG energy costs, depending on the comparative costs of electricity and diesel fuel.

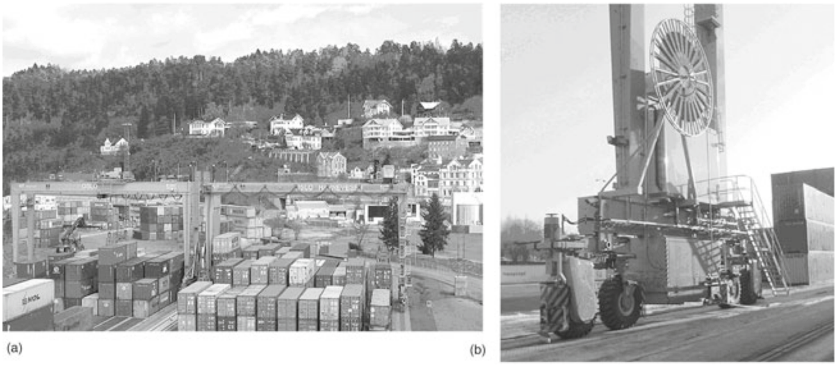

Fig. 3.5 a) Zero emission RTG crane, b) Cable feed of zero emission RTG crane

3.3.3 *Yard Tractors*

Yard tractors are used in transporting containers between the quay and the container yard (see Figure 3.4b). For this purpose, they are usually coupled with a container chassis or trailer respectively enabling a concurrent transfer of one 40 ft or two 20 ft boxes. Yard tractors are also typically used for internal transportation, such as rail container movements between the rail site and container yard, or transports between the empty depot and the quay wall.

3.3.4 *Operational Characteristics*

Yard tractors are commonly used in RTG terminals, due to their simple design and low capital, operating and maintenance costs. Yard tractors move containers on a terminal chassis (trailer) so they need to be loaded and unloaded by STS and RTG cranes. Usually operators try to minimize waiting times for cranes, especially for STS cranes, which results in a high number of yard tractors required. Based on Kalmar's overall cost estimates and customer input, usually 4–6 yard tractors are required against each STS crane in a bigger terminal. It is common to have more than 50% waiting time in a yard tractor work cycle in this type of application.

Because of the high number of yard tractors required for each STS crane, comparatively many operators are needed. This is not an issue in the low labor cost markets, where percentage of labor is small compared to the overall cost (capital, operating, maintenance and labor). According to Kalmar's overall cost estimates, high labor cost markets where percentage of labor can account to more than 50% of the overall cost, this is a significant disadvantage.

3.4 Operational Simulation

Kalmar's simulation program Port Optimizer® is used to model operations processes (see Figure 3.6), in order to get a realistic estimate of numbers for the Automated Shuttle Carriers® required for smooth container transport at terminal quayside. The operational scenarios supposed for simulation runs are especially characterized by a predetermined number and type of STS cranes, yard cranes as well as vessel loading and discharging sequences subsequently explained in full details.

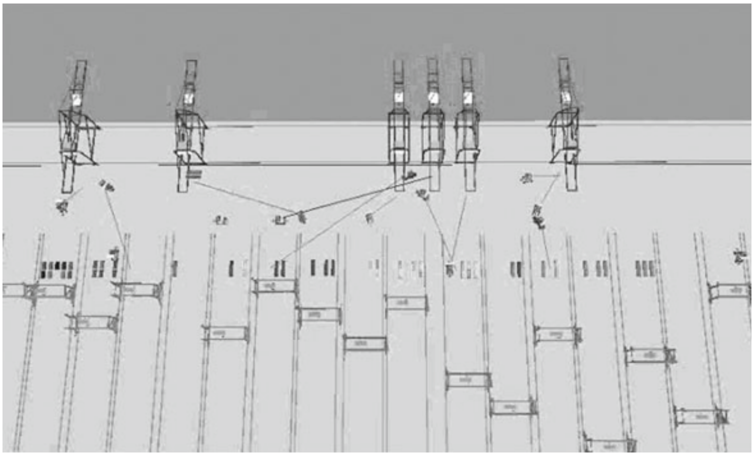

Fig. 3.6 Animation of Automated Shuttle Carrier® simulation (screenshot)

3.4.1 Input Data

Quayside section of a terminal with 6 STS cranes is simulated, with the following technical STS crane productivity (see Table 3.1):

- 2 cranes with single lift at 40 mph (moves per hour)
- 2 cranes with twin lift at 30 mph
- 2 cranes with tandem lift (dual hoist) at 22.5 mph

Target of the simulation is to get 45 containers per hour for average STS crane productivity, compared to the theoretical mean value of 48 containers per hour. The simulation is made on quayside operation, with a simulation period of 8 hours and with a fixed Automated Shuttle Carrier® fleet size. Regarding the number of employed carries two fleet sizes are considered for simulation, defining the modeled operations scenarios correspondingly (scenario I/II: 12/14 Auto Shuttles).

ASC operation is modeled as follows:

- 15 blocks
- technical productivity used in containers per block and hour: 1*21 containers (20 ft or 40 ft), *i.e.* 170s per work cycle (if no waiting)

Input data is given for each STS crane in each 4-hour shift (also see Table 3.1):

- hoist/spreader type: Single, twin or tandem hoist
- loading or discharging of vessel
- STS crane position
- sequence of using ASC modules (random with imports)
- technical productivity per shift and per hour (if no waiting)

Modeling of Automated Shuttle Carrier® operation is based on realistic parameter setting for vehicle speeds and handling times:

- maximum driving speed of 30 km/h
- acceleration speed of 0.5 m/s^2 (empty) and 0.4 m/s^2 (laden)
- deceleration speed of 0.5 m/s^2
- time for container pick up of approx. 12s
- time for container drop down of approx. 10s

3.4.2 Rules and Assumptions

The same fleet management rules are considered as in actual Terminal Logistic Systems developed by Kalmar. They enable an automated control of the Automated Shuttle Carriers® fleet, including vehicle pooling as well as flexible assignment of Automated Shuttle Carriers® to STS cranes and ASC lanes.

Based on extensive literature overview more in-depth information about simulation modeling in the field of container terminals, as well as decision support for automation of equipment control, is provided, *e.g.* by Huang et al (2007) or Stahlbock and Voß (2008). Automated Shuttle Carriers® make twin-lift moves only for import containers, 20 ft export containers are picked up separately by two carriers and

Table 3.1 Input data for simulation (logistics characteristics of STS cranes)

Theoretical Productivity (Containers per Hour)

Crane		0:00-4:00	4:00-8:00	Average STS	Min. STS	Max. STS
STS1	Handling Type	Twin	Twin	60.00	60.00	60.00
	Discharge / Load	D	L			
	X Position	40	68			
	ASC Modules	random	1,2,3,4,5,6			
	Time (sec.)	14,400	14,400			
	Cont. per Shift	240	240			
	Cont. per Hour	60	60			
STS2	Handling Type	Tandem	Single	42.50	40.00	45.00
	Discharge / Load	L	L			
	X Position	120	128			
	ASC Modules	5,6,7,8,9,10	5,6,7,8,9,10			
	Time (sec.)	14,400	14,400			
	Cont. per Shift	180	160			
	Cont. per Hour	45	40			
STS3	Handling Type	Twin	Tandem	52.50	45.00	60.00
	Discharge / Load	D	L			
	X Position	300	252			
	ASC Modules	random	7,8,9,10,11,12			
	Time (sec.)	14,400	14,400			
	Cont. per Shift	240	180			
	Cont. per Hour	60	45			
STS4	Handling Type	Tandem	Tandem	45.00	45.00	45.00
	Discharge / Load	D	L			
	X Position	328	308			
	ASC Modules	random	11,12,13,14,15			
	Time (sec.)	14,400	14,400			
	Cont. per Shift	180	180			
	Cont. per Hour	45	45			
STS5	Handling Type	Single	Twin	50.00	40.00	60.00
	Discharge / Load	L	D			
	X Position	356	364			
	ASC Modules	11,12,13,14,15	random			
	Time (sec.)	14,400	14,400			
	Cont. per Shift	160	240			
	Cont. per Hour	40	60			
STS6	Handling Type	Single	Single	40.00	40.00	40.00
	Discharge / Load	L	D			
	X Position	456	464			
	ASC Modules	11,12,13,14,15	random			
	Time (sec.)	14,400	14,400			
	Cont. per Shift	160	160			
	Cont. per Hour	40	40			
	Average	48.33	48.33	**Average Productivity of STS** **48.83**		
	Min	40.00	40.00			
	Max.	60.00	60.00			

moved to a twin-lift formation under the STS crane backreach. Tandem lift containers are moved separately, *i.e.* upcoming transport orders are executed by different vehicles. For completion of transport jobs Automated Shuttle Carriers® basically take up the shortest distance.

ASC operations are not simulated in full details, but a fixed productivity of 21 moves per hour is assumed per stack (except when waiting), performed by one crane at the quayside end of ASC modules. Also STS crane productivity is based on the input data, so actual productivity variations, due to breakdowns or operational disturbances etc., are not included. The latter simplifications are also applied to modeling the Automated Shuttle Carriers® and ASC operations. Furthermore, operational waiting times (if they occur) are considered by simulation of all types of equipment.

3.4.3 Simulation Results

The simulation results are shown in the following figures for both the 12 and 14 Auto Shuttle scenario. Their basis forms two simulation runs (one for each scenario), reproducing 8 hours operating time.

First, the average STS productivity of every shift is illustrated for each single crane and for all cranes measured by the number of handled container per hour (see Figures 3.7 and 3.8). Afterwards, the average overall STS productivity is quantified by the number of containers and crane moves per hour performed by all cranes in both shifts, on the average. Correspondingly, the average overall Automated Shuttle Carrier® productivity is presented for both simulation scenarios as well (see Figure 3.9). Based on the results of the simulation, two Automated Shuttle Carriers® per each STS crane are sufficient in order to achieve the required 45 container per hour average STS crane productivity. The average traveling distance (one way) for 12 Automated Shuttle Carriers® was approximately 200m. In existing smaller straddle

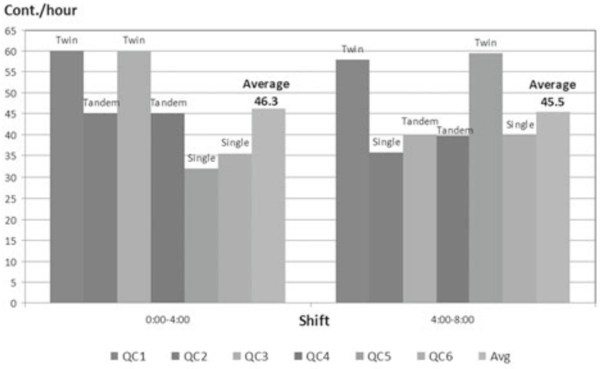

Fig. 3.7 STS Productivity: simulation results for a fleet of 12 Automated Shuttle Carriers®

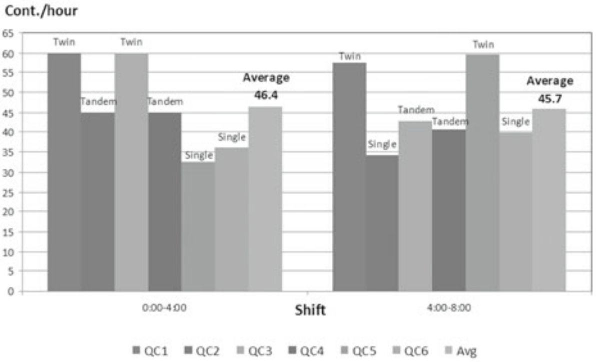

Fig. 3.8 STS Productivity: simulation results for a fleet of 14 Automated Shuttle Carriers®

carrier terminals (with similar or slightly longer traveling distances), usually two, and in bigger terminals frequently three, manual straddle carriers operate each STS crane. An average existing terminal, however, requires lower STS crane productivity, in the area of 30 containers per hour. Pooling of straddle carriers is normally not used in these container terminals.

Based on the above, it appears that two Automated Shuttle Carriers® per each STS crane, when working with ASCs, is a realistic number in the given scenario. This fleet size does not however include additional units required, due to operational disturbances, breakdowns and service needs. If manual Shuttle Carriers® are used together with ASCs without pooling, probably 2–3 units would be required per each STS crane, in order to cover times of peak productivity.

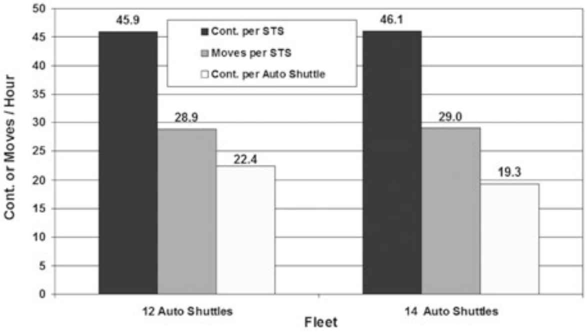

Fig. 3.9 Average STS crane and Automated Shuttle Carrier® productivities with different fleet sizes

3.5 Terminal Level Comparison (Yard Equipment)

A comparison is made for a theoretical import/export terminal, with a total of 6 STS cranes with an average productivity of 30 containers per hour. Rail or empty container movements are not included in the comparison. It is assumed that they remain the same in all system alternatives.

Number of operators is calculated based on total of 5 operators required per manned vehicle (see Table 3.2) considering three shifts per day as well as employee absence due to sickness, holiday, etc. For ASC system 5 yard cranes per STS are to guarantee smooth handling operation on the quayside and one operator is required per 4 yard cranes on the landside for the loading and unloading of road trucks by means of remote control. The latter are only calculated for control ASCs working at the landside end of yard blocks. Based on experience from RTG customers and assuming same productivity with zero emission RTG cranes, it is estimated that the following number of equipment and operators would be required in the terminal (see Table 3.2):

Table 3.2 Equipment fleet sizes and operator requirements of alternative handling systems

	per STS crane	total fleet size	operators
RTG crane	3	18	90
yard tractor	5	30	150
total			240
zero emission RTG crane	3	18	90
yard tractor	5	30	150
total			240
ASC	5	30	20[3]
Automated Shuttle Carrier®	2	12	0
total			20

As a result it is clear, and not surprising, that use of Automated Shuttle Carriers® gives significant labor savings with yard equipment operators. Naturally labor costs for STS cranes and other supporting equipment and activities, including maintenance, will remain the same. Since capital costs are clearly increased due to automation, the overall cost impact needs to be estimated case by case. In high labor cost markets the overall cost will most likely be reduced, whereas in low labor cost markets the overall cost may increase. Zero emission RTG cranes will in most cases reduce operating and maintenance costs, and this can be analyzed case by case.

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[3] Assuming an ASC system with two cranes per yard block on separate crane rails the use of 30 ASCs is associated with 15 container blocks in the yard area and 15 ASCs simultaneously working at the landside block ends (in peaks). As a result the block configuration requires 4 (15/4) remote control operators per shift (also to be multiplied by 5) and 20 operators in total.

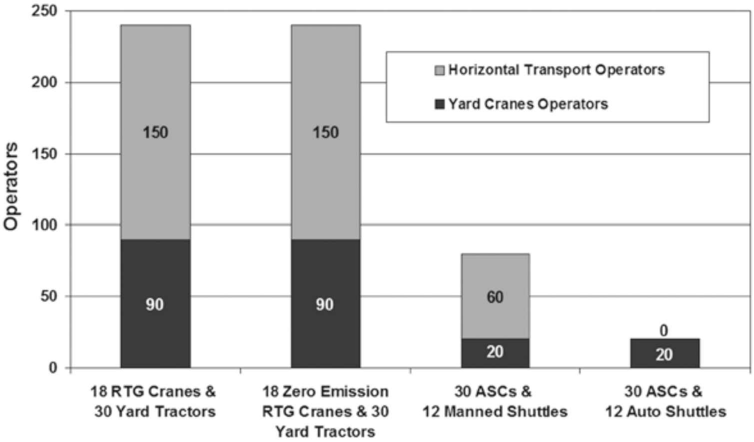

Fig. 3.10 Number of yard equipment operators needed in alternative handling systems

3.6 Environmental Impact Comparison

Average power usage and operating hours per year (estimated for each machine type) form the basis for calculation of total annual energy usage and emissions of operations systems considered for investigation. Operating hours for equipment was assumed to be 5,000 hours per year, except 4,000 hours for equipment used on the quayside only, *i.e.* for yard tractors and Automated Shuttle Carriers. Annual energy usage is basically represented by *m*ega*w*att *h*ours (MWh) for all systems (units).

Emission calculations for equipment are based on type approval tests for tier 3 engines. Only local emissions are analyzed. Neither for zero emission RTG cranes nor for ASCs energy regeneration is included. Emission estimation considers especially the amount of *n*itrogen *ox*ide (NOx), *h*ydro*c*arbon (HC), *c*arbon mon*o*xide (CO) and *p*articular *m*atter (PM) emissions produced by different machine types.

An overview of characteristic figures for energy usage and environmental emissions of terminal equipment discussed in the foregoing sections is provided in the footnote below.[4]

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[4] Annual energy usage and emissions per vehicle or crane.

Diesel electric RTG crane (Kalmar E One):

Estimated average power usage per machine:	70 kW
Estimated operating hours per year:	5,000h
Total energy usage per machine and year:	350 MWh

Tier 3 level emissions per year per machine:

NOx + HC:	4,0 g/kWh * 350 MWh =	1,400 kg
CO:	3,5 g/kWh * 350 MWh =	1,225 kg
PM:	0,2 g/kWh * 350 MWh =	70 kg

Zero emission RTG crane (Kalmar):

Estimated average power usage per machine:	50 kW

Based on values measured per machine and year, we can calculate the annual energy usage and emissions for the whole terminal fleet. Emissions and energy consumption for other than the main container yard equipment is not included in the system comparison, assuming that they remain the same in all alternatives. Calculations given below lead to the annual energy usage of each operations system. Additionally, more detailed results of the energy comparison can be seen in Figure 3.11.

Diesel electric RTG cranes with yard tractors:
18 * 350 MWh + 30 * 160 MWh = 11,10 GWh

Zero emission RTG cranes with yard tractors:
18 * 250 MWh + 30 * 160 MWh = 9,30 GWh

ASC cranes and Automated Shuttle Carriers®:
30 * 375 MWh + 12 * 320 MWh = 15,09 GWh

Following, calculations of environmental emissions are represented for all system alternatives. Figure 3.12 gives an overview of the emission comparison including an illustration of the equipment related impact.

Estimated operating hours per year: 5,000h
Total energy usage per machine and year: 250 MWh
No local emissions

Yard tractor (Kalmar PT122):
Estimated average power usage per machine: 40 kW
Estimated operating hours per year: 4,000h
Total energy usage per machine and year: 160 MWh
Tier 3 level emissions per year per machine:
NOx + HC: 3,16 g/kWh * 160 MWh = 505.6 kg
CO: 1,50 g/kWh * 160 MWh = 240.0 kg
PM: 0,10 g/kWh * 160 MWh = 16.0 kg

ASC (Kalmar):
Estimated average power usage per machine: 75 kW
Estimated operating hours per year: 5,000h
Total energy usage per machine and year: 375 MWh
No local emissions

Automated Shuttle Carrier® (Kalmar SHC250 with SCR technology):
Estimated average power usage per machine: 80 kW
Estimated operating hours per year: 4,000h
Total energy usage per machine and year: 320 MWh
Tier level 3 emissions per year per machine:
NOx + HC: 3,30 g/kWh * 320 MWh = 1,056.0 kg
CO: 0,35 g/kWh * 320 MWh = 112.0 kg
PM: 0,09 g/kWh * 320 MWh = 28.8 kg

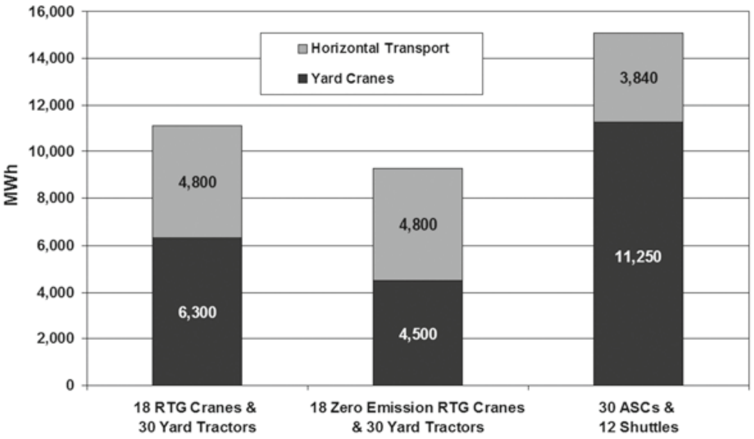

Fig. 3.11 Energy usage of compared handling systems

Diesel electric RTG cranes with yard tractors:
NOx + HC: 18 * 1,400 kg + 30 * 505.6 kg = 40,368 kg
CO: 18 * 1,225 kg + 30 * 240 kg = 29,250 kg
PM: 18 * 70 kg + 30 * 16 kg = 1,740 kg

Zero emission RTG cranes with yard tractors:
NOx + HC: 0 kg + 30 * 505.6 kg = 15,168 kg
CO: 0 kg + 30 * 240 kg = 7,200 kg
PM: 0 kg + 30 * 16 kg = 480 kg

ASC cranes and Automated Shuttle Carriers®:
NOx + HC: 0 kg + 12 * 1,056 kg = 12,672 kg
CO: 0 kg + 12 * 112 kg = 1,344 kg
PM: 0 kg + 12 * 28.8 kg = 345.6 kg

In the results we can see clear reduction of emissions for both zero emission RTG cranes with yard tractors and for Automated Shuttle Carriers®. The main reductions, unsurprisingly, come from using electric power instead of diesel engine power, as used in the conventional RTG cranes. The overall energy usage will however go up with ASCs, mainly due to the much increased gantry drive and more weight moved (both crane and load). The energy consumption of zero emission RTG cranes can be further reduced by energy regeneration (not included in the calculations).

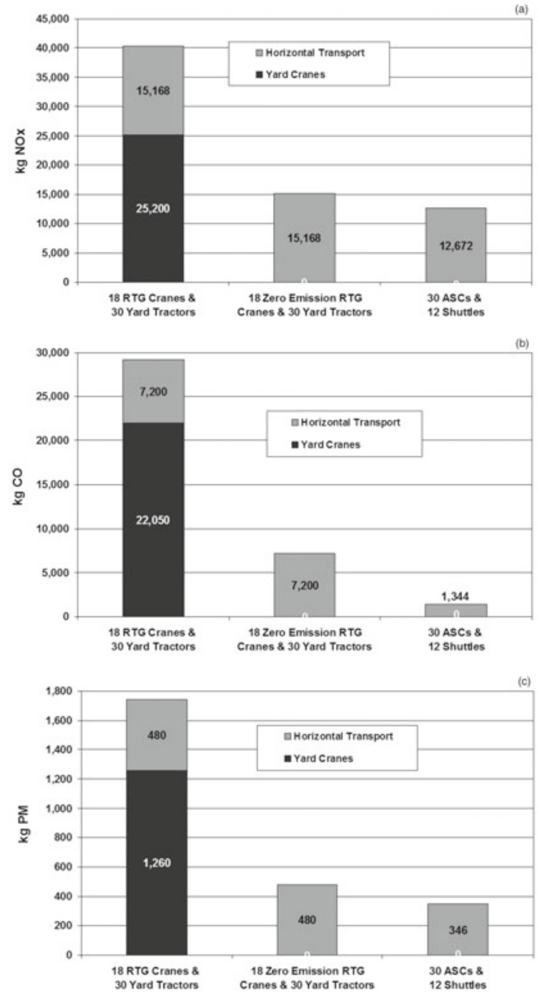

Fig. 3.12 a) NOx + HC emissions, b) CO emissions and c) PM emissions of compared handling systems

3.7 Conclusions

In the manning requirements we can see that ASC cranes together with Automated Shuttle Carriers® requires significantly lower number of operators. Even with manual Shuttle Carriers®, which are not analyzed here, the lower number of transport vehicles will clearly reduce the required number of operators, when compared to the RTG crane concept with yard tractors.

This will naturally result in lower labor costs, which will lower the overall cost in high labor cost areas. These include areas such as Western Europe and North

America, where labor accounts for more than 50% of the overall cost. In low cost labor countries, such as China or India, the low share of labor costs means that higher capital costs for automation are usually not justified.

We can see that in terms of overall power consumption, the RTG crane concept is better. This can be explained with the fact that in ASC operations there is much more gantry drive than in RTG operations and also more weight moved (both crane and load).

In terms of emissions however the Automated Shuttle Carrier® concept was clearly the best and the zero emission RTG crane alternative second best. The reason for Automated Shuttle Carrier® concept, being somewhat better than zero emission RTG concept, is the smaller fleet size and significantly shorter traveling distances of the transport equipment.

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Chapter 4
Sustainable Container Terminals: A Design Approach

Joan C. Rijsenbrij and Armin Wieschemann

Abstract
The future will bring increasing demands from society for a better quality of life and for more sustainable designs also in port handling facilities. Moreover, scarcity of land forces port authorities to realize higher area utilizations. Terminal operators have equal objectives, but on top of that they are looking for cost reductions through decreased life cycle cost (energy consumption, maintenance, life-time, etc.). Many of these topics have their impact on the design of terminal (stack) handling systems and for that reason both the terminal operators (in their systems specs and equipment specs) and the system (equipment) suppliers are in the process of installing more sustainable, environmentally friendly and cost-effective handling systems. In this chapter the authors present a design approach and directives to be applied for stacking systems and connected transportation systems in container terminals. Covered topics are: performance issues stack configurations, strategies to realize more sustainable designs and measures to increase cost-efficiency and to reduce energy use and eco-impact. The chapter shows the challenge how to balance service requirements, costs and demands for sustainability.

4.1 Introduction

During the last decades the world showed a growing awareness of the limited re-

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sources on earth and an increasing concern about our environment and ecology. This is reflected in rising demands from the society for a better quality of life, preservation of nature and more sustainable designs for products as well as facilities and services. Fortunately the younger people support the aggravating directives for a more sustainable world and also the industry has accepted these trends and has embraced the challenges to develop sustainable designs for products, facilities and services.

Impressive results are already shown in the automotive industry: electrically driven vehicles will enter the world in the next decade on a much larger scale. Especially for drives, electric energy can be applied in a sustainable way as electric energy is not dependent on one resource type (*e.g.* crude oil), and will be available for thousands of years. The dominant use of fossil fuels for energy-generating will gradually be replaced by renewable energy sources like wind energy, hydro power, solar energy etc. (obviously in the course of many decades). In addition, nuclear energy can be used, which is sustainable in terms of air pollution and climate change although the nuclear waste storage asks much more attention.

In an approach for sustainable designs in container terminal operation it is necessary to take some future trends into account, being:

- a probable further growth in yearly port handling volumes resulting in capacity demands and increased environmental impact.
- increased port handling performance as shipping lines and inland transportation companies require predictable, limited turnaround times even for their large 10,000 – 15,000 TEU container vessels and simultaneously during landside rush hours. This may cause increased peak demands and logistic complexity.
- growing dominance from shippers and consignees with a probable negative impact on landside stochastics and logistic control (last-minute changes, unknown modal connections, increased housekeeping).
- a demand for cost reduction in the logistic chain, resulting in lowering (or even avoiding) warehousing and regional distribution centers. This could be detrimental for the dwell time of containers in the terminals and the resulting consequences for area demand and service levels.

Over the last years one issue has been dominant: cost control. Unfortunately, for terminal designs the focus is often directed to minimizing investment cost instead of minimizing the yearly operating costs within a certain terminal concept. For equipment selection functionality and costs dominate over sustainability.

Recently, management experts and environmentalists advocate an approach towards minimum life cycle cost, including the cost of environmental impact. Cost analysis methods like *Total Cost of Ownership* (see Geißdörfer (2009)) or *Life Cycle Costing* (see Flanagan (1989)) can be used to calculate a products total expense, including the costs for acquisition, the operating costs and the costs for disposal. A life cycle cost analysis should also include the materialized impact of the rate of sustainability from equipment, facilities, operational organization and outsourced services.

However, terminal equipment manufacturers have experienced that the short-term economic vision of many terminal companies result in risk-avoiding management, including reluctance against new technologies that will bring a better future cost performance and that will improve sustainability.

In this chapter we will emphasize on the philosophy and practical application of systems and technologies that will support sustainability of container terminals and that will contribute to lower overall life cycle cost, including the impact on environment and ecology.

4.2 Sustainability and the Container Handling Industry

Already for several decades, sustainability is a design aspect with (necessarily) a growing importance. Unfortunately there is not one clear definition of sustainable design, however, in general sustainability is known as: “Meeting the needs of the present, without compromising the ability of future generations to meet their own needs.”

Nowadays most designers recognize three major aspects to be considered in their design activities:

- *People*: systems or equipment should be such that social aspects are not violated but should be improved.
- *Planet*: systems, equipment and processes should not damage the natural environment in which they are active. Natural resources and the ecology should be safeguarded.
- *Profit*: systems and processes should focus on reasonable profits to survive and deliver services to the environment.

In this respect sustainability is often characterized by four activities: *Reduce*, *Reuse*, *Recycle* and *Regulate*. In 1989 the World Business Council for Sustainable Development defined a new attitude: Eco-efficiency, to be achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with earth’s carrying capacity.

Based on the above the European Environmental Agency came with the following definition: Eco-efficiency is “the amount of environment used per unit of economic activity”. Manufacturers like Nokia have translated this broad definition into design directives *e.g.*: minimized use of energy, material, toxic dispersion, extended durability (lifetime), maximized use of renewable resources and increased recycling.

More recent, Braungart et al (2007) and McDonough and Braungart (2002) presented their Cradle-to-Cradle design approach to be considered as eco-effectiveness. In that design approach the material intensity per service unit is irrelevant as long as the output can serve as productive resources (input) for natural systems (McDonough and Braungart (2002); Braungart et al (2007)).

In general, the above definitions and approaches may be applicable for many products; however, do they fit for the multidisciplinary terminal design and operation? When focussing on container terminals the following consideration can be made: The primary product of a container terminal is the service to the connecting modes of transport (deep-sea, feeders, rail, road, and barges), basically minimizing waiting times for the intermodal activities (the swap from mode to mode).

The present understanding of sustainable terminal design is mainly directed towards eco-efficient equipment, facility designs and operation (generally known as: "to get more from less"). In the view of the three Ps (*P*eople, *P*lanet, *P*rofit) and eco-efficiency, the following areas for sustainability in container terminals can be pointed out:

1. Reduction of energy use

- electrical controls of equipment drives and energy supply systems
- more efficient drive-lines
- avoidance of diesel-driven equipment
- critical approach of lighting levels and the application of energy-efficient armatures/lighting systems
- covered areas for reefer-containers (to avoid sun-radiation)
- application of renewable energy sources (*e.g.* for heating/air-con, mobile equipment)

2. Eco-efficient operation/design

- application of eco-friendly equipment (reduced sound emissions, reduced toxicity, cold-ironing for vessels, etc.)
- best practices for area utilization, especially in the areas for transportation and stacking
- socio-technical approaches in participative management and operational control methods

3. Durable facilities and handling systems

- terminal facilities with a long lifetime and low maintenance demand designed with renewable/reusable materials, *e.g.* high quality concrete, wooden structures, glass panels (see Giessen (2002))
- handling equipment designed for 20–30 years operational life
- modular designed components allowing for a future expansion without major modifications

When it comes to a "Cradle-to-Cradle" approach, this is rather complicated for a terminal. There is a limited amount of output (waste) during operation that could be reused. The major output may arise in the demolition stage of a terminal and that is not often the case, as many terminals are upgraded from time to time (every 10–25 years).

So far there is one area where Cradle-to-Cradle has potential: the operational lease of equipment and/or systems during a certain period (see Braungart et al (2007)). At the end of such a period the equipment will be returned to the original manufacturer, who will recover many materials (components) to be used again for the creation of new products. Although theoretically feasible, this still is a situation for a further future.

4.3 Design Approach for a Sustainable Container Terminal

Only in the last decade the awareness about the need for more sustainable designs for terminal handling systems and overall terminal design is growing. Some terminal operators encourage developments themselves, but the majority of such developments have been initiated either by port authorities (governmental bodies) or system (equipment) suppliers. In general there are some major directives to reach at a sustainable container terminal design:

- minimize (or even avoid) transportation, both horizontally (traveling) and vertically (hoisting/lowering)
- when transportation (displacement) is required, then do it as eco-efficient as possible and be critical on speeds and demands for strict sequential operations
- when energy is necessary, then minimize the use (proper drive line design, avoid too much dead loads, install controlled acceleration/deceleration etc.) and where possible, apply renewable energy sources
- minimize high-valued resources such as land area, access channels and if new port area has to be created, integrate an eco-friendly design combined with an encouragement of new biotope potentials around such new port development areas (Figure 4.1 presents an example of such sustainable development)
- apply reusable components and recyclable components/materials

On top of that, it is recommended to balance the various connected handling/transportation processes, active in the overall logistic chain (Saanen (2004); Dobner and Saanen (2002)) *e.g.*: *vessel – quay wall – stack – landside interchange* (or *vessel – quay wall – stack – quay wall – vessel*) and reverse (see Figure 4.2).

Considerable cost savings and contributions to sustainability can be obtained from the following exercises:

- limiting the amount of sub-processes
- avoidance of transport (looking for minimized distances, reduction of re-shuffles and housekeeping)

Fig. 4.1 Storage of empty containers behind dunes without horizon pollution

- balancing processes on the base of realistic operational output capacities (including stochastic disturbances) instead of theoretical technical equipment capacities

It is always the output of the entire logistic chain that counts, so: avoid the overdesign of one or some of the sub-processes. Unfortunately, during the last decades of growing scales in containerized transportation with larger peak demands there has been a growing gap between installed technical capacity and realized operational capacity.

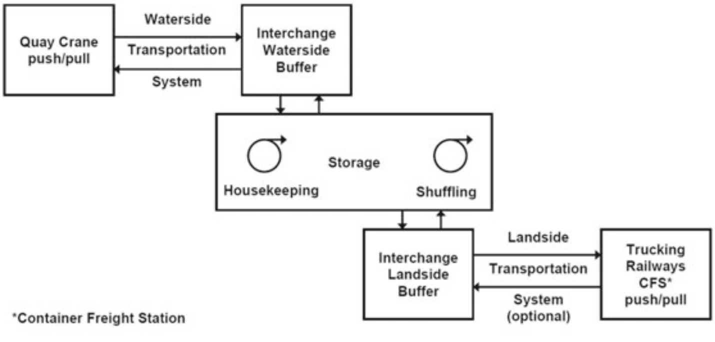


Fig. 4.2 Connected processes in terminal handling systems

This is a negative development for sustainable container terminal design. To summarize, the approach for a sustainable terminal design should be:

1. Design a logistic concept with inherent characteristics for a sustainable handling and internal transportation.
2. Select handling systems and related equipment with a low impact on the environment and a low (preferable electric) energy consumption.
3. Design a logistic control system with optimizing algorithms for minimized interchange waiting times and maximized utilization of the installed functional equipment characteristics. This should result in operations system capacities close to the achievable technical capacities.

The achievement of the best sustainable design (if that's the objective) can only be realized if all actors involved balance their interests with a system approach in the overall design process.

4.4 Stacking and Transportation, Dominant for Sustainable Designs

When it comes to sustainability that can be influenced by the terminal operator (in the terminal design stage and during the terminal's operational life), stacking and transportation are important design components.

On the waterside and the landside, other actors than the terminal operator should incorporate measures/behaviour/design that support sustainable terminal operation. The three major terminal design components will be covered below.

4.4.1 Waterside and Landside Handling Systems

On the waterside two major components determine the impact of sustainability: vessels and quay cranes.

Due to the tremendous scale developments in the last decades, vessels nowadays have a noticeable environmental impact. At first there is their demand for wide access channels and turning basins of sufficient depth and then there is the need for amply designed quay walls (depth, fender forces, bollard strength, etc.), provided with large quay cranes offering sufficient handling productivity to ensure a short stay in port (preferably $<$ 24h). The eco-impact of vessels is increasingly compensated by the creation of "new nature" to be financed by port authorities or regional bodies.

Increased pollution from diesel engines (main propulsion and auxiliaries) is now being controlled by all kinds of "clean air initiatives" pushing towards a "cold-ironing", *i.e.* asking vessels to shut-off all their diesel engines when alongside the berth and to connect to electric supply from the shore. Although this is a major contribution to sustainability it will ask for a massive power supply and investment as many larger vessels use some *M*ega*W*atts (MW) in power (on-board reefer connections, ballast pumps, air-con systems, ventilation, etc.)

When it comes to quay cranes, we see the same increased demands for power supply (sometimes up to 4 MW installed in drives per crane), noise pollution and the use of many types of scarce materials. On top of that, the quay cranes significantly contribute to a terminals horizon pollution, which means that the visual attractiveness of the environment is affected by *e.g.* large steel structures (up to 125m high) and eye-catching coloring. The continuing drive for more productive cranes has resulted in lifting capacities up to 125 tons with an outreach of 70m and lifting speeds up to 2.5 m/s at rated load. Unfortunately the gap between technical productivity (crane cycles/h) and operationally realized productivity has increased. So, from a sustainability point of view the present-day crane purchasing policy has quite some disadvantages.

On the landside, mainly trucking and railroad companies deliver and collect containers and the terminal can only contribute little in this area as well. The avoidance of waiting trucks and trains is important, as these result in a waste of energy and a need for extra space. For railroad operation it is important to install an electric driven air compressor station to supply pressured air for the trains before leaving the terminal (main break test). Nowadays, this is mainly done by a diesel-electric locomotive – not a very sustainable type of air compressor.

In order to avoid an overcapacity of equipment on the landside, a pre-notice of arrival information or even strict agreements on pick-up times (*e.g.* truck appointment systems) can help to avoid handling equipment and truck waiting and thus limit unnecessary emissions and energy waste.

As long as shipping lines, truckers, railroad companies, port authorities and terminal operators do not balance their varying controversial interests, most of the operators will follow the shipping line's requirements. So, in this area the terminal operator will be limited to contribute to sustainability.

4.4.2 Stacking Systems

In the design of container stacking systems a system approach should be applied in order to fulfil the demands for today's and future terminal container handling activities and to balance the various conflicting requirements (cost, service, working conditions, sustainability, etc.); see Veeke et al (2008).

Stacking systems must be specified through a proper description of the expected performance (handling productivity, eco-efficiency). This should be defined through quantitative data and the system conditions, under which the expected quantitative goals should be realized. Some of the major functional characteristics for stacking systems are presented below:

- **Balancing stack capacity and stack handling capacity**
  Although the name "stacking systems" does suggest that these systems are made for stacking, the handling capacity (receiving and delivering containers both to

the land and waterside) is at least as important. Increasingly, terminal operators are assessed on their ability to serve the vessels with high hourly berth productivity and on their response time to truckers or railways when they call for a pick-up load. The handling capacity is not only depending on the type and numbers of installed stacking equipment. In addition, the interfacing with the interconnected transport systems is of importance, as well as the average stacking height, the chance on shuffles and last minute changes. In many cases the installed technical handling capacity of equipment is reduced by 30–50 % due to interfacing, waiting for orders, shuffles etc. Here, stack strategies and assignment algorithms can contribute to more eco-efficient designs.

- **Flexibility for container types and sizes**
  The more variations in container sizes and types exist and the larger the amounts, the more complex a stacking system layout will be and that will influence the area utilization, the optimum average stack filling and the stack handling capacity.
- **Last minute changes**
  In the beginning of containerization, the on-wheeled system (containers on road and/or terminal chassis in the yard) gave maximum possibilities for last minute changes. A maximum random pick-up was possible, but large variations in stack location result in large variations in transport cycle distances, which negatively influence the overall system productivity. Today, the majority of stacking systems allow stacking from 1-over-3- up to 1-over-8-high. Here, last minute changes will really destroy stacking system productivity. However, the stacking system concept and the equipment design can decrease the negative impact of last minute changes.
- **Potential for buffering**
  The stochastic nature of terminal handling processes, the demand for proper sequencing (*e.g.* when loading a vessel) and the coupling of 2–4 processes into one logistic chain (*e.g.* from vessel deck to reefer stack) cause large variations in handling cycle times and costly waiting for equipment and its operators (if manually driven). The availability of buffers, *e.g.* at interchange areas, can help to improve productivity and avoid waiting times and thus will avoid a waste of energy (see Figure 4.3).
- **Interfacing with connected transport systems**
  In these “handshake” operations the preciseness of positioning must be defined and such tolerances for positioning must be met, regardless of weather conditions, load magnitude, eccentricity of load center of gravity, etc. (see Rijsenbrij (1996)).
- **Reliability**
  Especially for equipment working on runways (rail-mounted, rubber-tyred) reliability is of utmost importance. Maintainability during operation, tele-diagnostics, the ease of access to vital equipment components and the possibilities to ex-

Fig. 4.3 Buffer and interchange area between transportation and stacking

change components in running condition are important characteristics that contribute to sustainability (increased productivity, less back-up equipment).

All the above functional demands must be translated into a sustainable stacking system design covering issues such as: noise levels, water and air pollution, the use of scarce material, the area demand, the consumption of energy and the possibilities for the application of recyclable materials. Energy use and pollution can be influenced by:

- total equipment mass
- drive line configuration
- speeds and acceleration/deceleration rates of the main-drives
- type of energy supply (fossil fuel, electricity, fuel cell)
- overkill on auxiliary drives/provisions

When it comes to the use of scarce material, there is an increasing demand, often for lifetimes over 10 years (decreased amortization, less training efforts, sustainable design). In such cases, the resistance against fatigue loads is of interest. In many cases the underestimation of fatigue loads both for the equipment and the rail support/pavement has resulted in excessive maintenance cost and reduced lifetimes.

A last but not least topic is the area demand, determined by a stacking system concept. Decreased area demands are not only welcomed by the society (less eco-impact), but also transportation distances will decrease and that again contributes to sustainability.

Today there are many different solutions for stacking systems, each with its own typical characteristics. The regularly applied systems for full containers (defined by their handling equipment types) are:

- reachstacker (top lifter)

- straddle carrier (1-over-2- or 1-over-3-high)
- *R*ubber-*T*yred *G*antry (RTG) crane (up to 1-over-6-high)
- *R*ail-*M*ounted *G*antry (RMG) crane (up to 1-over-6-high)
- *O*ver*H*ead *B*ridge *C*rane (OHBC) (up to-1-over-8)

When focusing on a sustainable terminal design, the selection of a reachstacker or straddle carrier concept is not attractive due to their diesel drives (fossil fuel consumption), their manual control (damages) and low to medium amount of TEU stack capacity per hectare.

In the last decades, the preference was increasingly directed towards RTG and RMG stacking concepts, where the latter concepts can be easily robotized as well (see Rijsenbrij and Wieschemann (2006)). It should be noted that savings in labor (from automated handling systems) are not only attractive for the resulting reliable (predictable) performance, the long-term cost control and reduced damage cost. In addition, this labor reduction contributes to sustainability as well as less people are commuting to their (far away) work place and less people need less terminal facilities (canteen, wash rooms, offices, etc.) and less consumables.

Despite this direct gain in sustainability for the terminal, the overall benefits and disadvantages of terminal automation for the society is a frequently discussed issue and goes beyond the topic of this paper.

For an eco-efficient choice between RTG or RMG stacking concepts, three topics are of interest: the energy use, the container travel distances and the overall stack area utilization (*e.g.* amount of TEU stack capacity per hectare).

- **Energy use**
  In general, the energy use per container movement is much larger when applying RTGs. Normally this type of equipment has a diesel-electric drive which is disadvantageous compared to the electrically powered RMGs. The recent introduction of RTG drivelines with energy-storage systems or hybrid power-trains has lowered the hourly fuel consumption, but still RTGs need fossil fuel which is transferred into electric torques in a rather inefficient way (diesel engine efficiency is about 35%). Also the traveling on rubber tyres requires more traveling power (due to the 10–15 times larger rolling resistance factor of tires), although this phenomena can be compensated by limiting the RTG traveling (container is received/delivered at the specific container stack position) and RTG mass.

- **Container travel distances**
  A real contribution to sustainability is the minimizing of container travel distances, which can be influenced by the selection of interchange locations. There are basically two principles: either the crane travels to the container (front-end interchange) or the container is traveling to the crane (parallel interchange). The latter will result in shorter crane cycle distances, but increased transportation distances (see Figure 4.4) and the resulting demand for transport equipment with their environmental impact.
  Figure 4.4 clearly shows the short transport distances on the water- and landside for a front-end interchange concept. The concept realizes the most direct trip from water- to landside (or reverse) and this traveling is generally done by

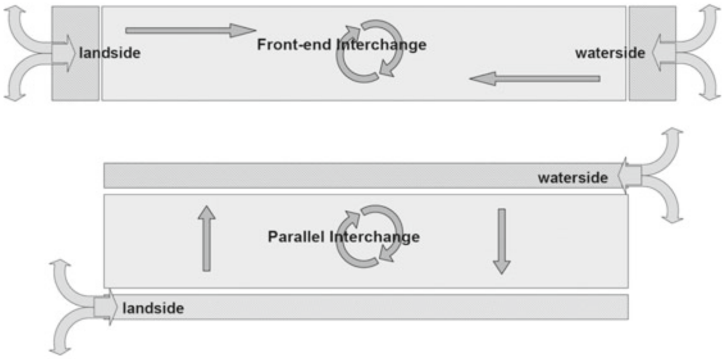


Fig. 4.4 Interfaces at stack ends or alongside the stack

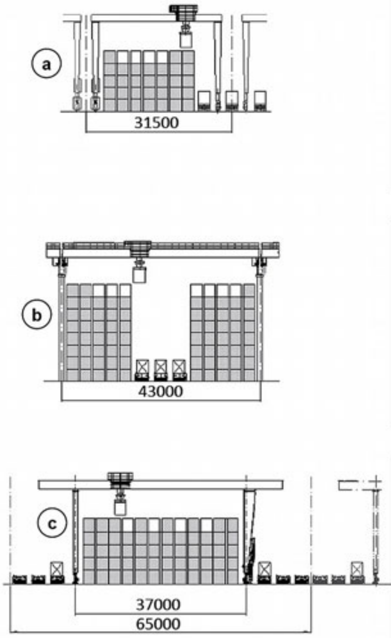
RMGs with a low rolling resistance but a rather high mass. Nevertheless it is a low-energy activity in comparison to RTG stacking systems, as travel speeds are limited to 4–4.5 m/sec and RMG stacking cranes are commonly equipped with electrical drives (*i.e.* no inefficient energy transformation and the potential for supply with renewable electric energy).

The parallel interchange concept includes longer travel distances, generally realized by rubber-tyred transportation equipment such as tractor-trailers, multi-trailers or shuttle carriers. In these RTG stacking concepts, the increased travel distances are very obvious (see later Figures 4.11 and 4.12). But on top of that, this transport equipment is manually controlled in most cases, resulting in the typical driver behavior: push the throttle, gas is paid by the employer.

In both concepts, truckers can collect or deliver their container directly in the stack, but the parallel-interchange asks for much longer traveling with a road truck which is overpowered for driving at the terminal (speed < 30 km/h).

There are two more topics of interest. Firstly, the front-end interchange concept automatically includes a proper separation between internal and external (road trucks) transportation. This is an interesting safety aspect and reduces the risk of damages. Secondly, when it comes to housekeeping (pre-organization of stacking) the parallel interchange concept in many cases requires internal transport whereas the front-end concept normally realizes housekeeping within the stacking-module done by the RMG.

- **Stack area utilization** (see Figures 4.5 and 4.6)
  The growth of terminal throughput, sometimes deteriorating container dwell times and increasing peak demands (increased call sizes from vessels and trains), requires more and more stack capacity and at the same time the society is getting more reluctant to provide scarce land for terminal operation. Thus, today's trend for stack handling systems goes towards higher density stacking, improved productivity both on the water- and landside and preferably lower costs per move.



RTG	7 wide / 1 over 5 high
Cross section (gross):	35 TEU
Recommended operational cross section:	31 TEU
Operational stack capacity per module:	31 x 50 = 1550 TEU
TEU ground slots per module	350 TEU
Module area* (length x width)	345 m x 31.5 m
Max. operational area utilization:	1426 TEU/ha

OBC	10 wide / 1 over 8 high
Cross section (gross):	80 TEU
Recommended operational cross section:	73 TEU
Operational stack capacity per module:	73 x 50 = 3650 TEU
TEU ground slots per module	500 TEU
Module area* (length x width)	325 m x 43 m
Max. operational area utilization:	2612 TEU/ha

RMG	12 wide / 1 over 5 high
Cross section (gross):	60 TEU
Recommended operational cross section:	56 TEU
Operational stack capacity per module:	56 x 50 = 2800 TEU
TEU ground slots per module	600 TEU
Module area* (length x width)	325 m x 65 m
Max. operational area utilization:	1325 TEU/ha

* length refers to a module of 50 TEU and the required interchange area

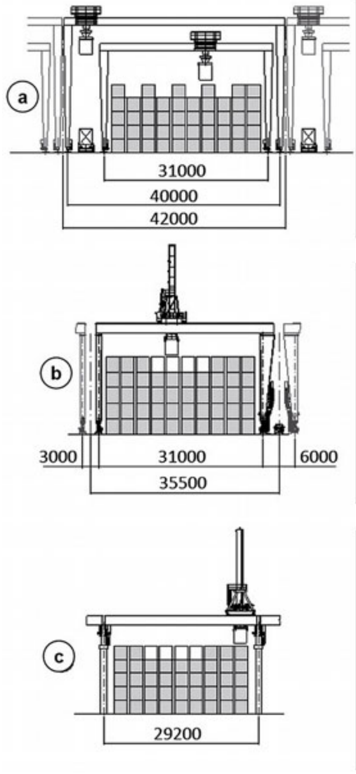
Fig. 4.5 Area utilization of some parallel interchange stacking concepts

Figures 4.5 and Figure 4.6 present a summary of some parallel and front-end interchange concepts including their maximum area utilization (based on a stack module of approx. 50 TEU long and including transport lanes and interchange area).

It should be noted that the max. operational area utilization must be reduced due to the need for workability which varies per concept (*e.g.* workability requirements of concept a) and b) in Figure 4.5: 65%; workability requirements of concept a), b) and c) in Figure 4.6: 85%).

One option for more storage are (cantilever) parallel interchange concepts with 5- to 8-high stacking and applying RTGs, OHBCs or RMGs. However, the area utilization suffers from driving lanes for landside and waterside traffic (see Figure 4.5). For manually operated systems unattractive waiting times (= waste of fuel and other scarce materials) will arise, as these concepts operate in a mix-up of unpredictable landside traffic together with high-performance internal waterside traffic.

When it comes to housekeeping (increasingly required, when asking for high handling productivity combined with 5- or 6-high stacking) the RTG concept or wide-span OHBCs or cantilever RMGs will result in substantial energy and scarce material demands.



RMG (nested)	**10 wide / 1 over 5 high**
Cross section (gross):	50 TEU
Recommended operational cross section:	46 TEU
Operational stack capacity per module:	46 x 50 = 2300 TEU
TEU ground slots per module	500 TEU
Module area* (length x width)	364 m x 42 m
Max. operational area utilization:	1504 TEU/ha

RMG	**10 wide / 1 over 5 high**
Cross section (gross):	50 TEU
Recommended operational cross section:	46 TEU
Operational stack capacity per module:	46 x 50 = 2300 TEU
TEU ground slots per module	500 TEU
Module area* (length x width)	364 m x 35,5 m
Max. operational area utilization:	1780 TEU/ha

OBC	**9 wide / 1 over 5 high**
Cross section (gross):	45 TEU
Recommended operational cross section:	41 TEU
Operational stack capacity per module:	41 x 50 = 2050 TEU
TEU ground slots per module	450 TEU
Module area* (length x width)	364 m x 29,2 m
Max. operational area utilization:	1929 TEU/ha

Fig. 4.6 Area utilization of some front-end interchange stacking concepts

> An even better area utilization option is the use of front-end-interchange RMG stacking modules (see Figure 4.6). The rail mounted cranes normally have an electric power supply and the cranes show a long lifetime, high reliability and low maintenance costs. The RMGs are running on fixed rail tracks and land- and waterside vehicles are no longer supposed to enter the stack area itself. Moreover, the transfer of containers from water- or landside into the stacking yard is now realized by the stacking crane itself ("crane travels to container").

There is an ongoing interesting discussion around the three different layout concepts for the attractive high-density stacking with front-end interchange concepts (see concept a), b), and c) in Figure 4.6). Figure 4.7 gives an artist's impression of the general arrangement of these three concepts. All concepts are using two stacking cranes (RMGs or OHBCs) arranged on one storage module which allows the serving of road trucks without disturbance of the waterside vessel operation. However, concept a) in Figure 4.6 allows a crossing of cranes to the detriment of an additional crane track per module. The cross sections (Figure 4.6) show the area utilization of the various stacking concepts. So far the selection has not only been based on area utilization, but on service, redundancy and costs as well. However, the trend is recently towards the high-density alternative B.

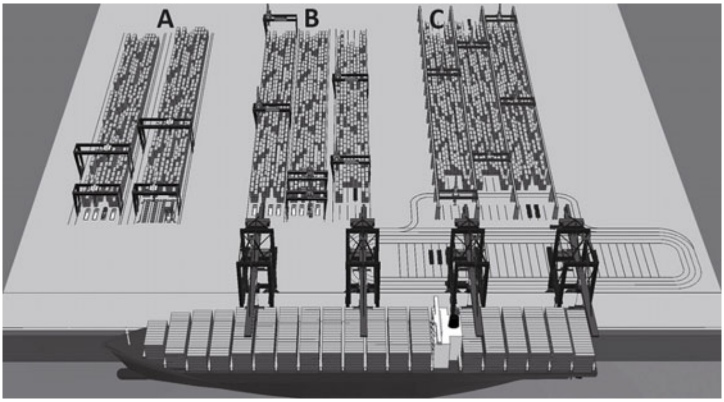


Fig. 4.7 Front-end interchange concepts with rising area utilization (from A to C)

4.4.3 Terminal Transportation

Large and medium-sized terminals apply four types of internal transportation for the connection between waterside, landside and RTG or RMG stacking concepts (recall that the reachstackers and the straddle carriers were ignored due to their environmental impact). Figure 4.8 shows these four types: *T*ractor-*T*railer (TT), *M*ulti-*T*railer *S*ystem (MTS), *Sh*uttle *C*arrier (ShC) and *A*utomated *G*uided *V*ehicle (AGV) ranked by decreasing environmental impact (based on fuel consumption per container transport determined by fuel consumption per equipment hour, cycles per hour and transport capacity per cycle).

Diesel-mechanically driven TTs, MTSs and ShCs respectively take about 10, 14 and 22 liter of fuel per operating hour. In case of diesel-electric drives, this hourly consumption decreases towards about 16 liter/h (ShC) or 7 liter/h (AGV). These figures can not be directly translated into an eco-impact per transported container, as this is influenced by stacking system alternative, start-stop arrangements (*e.g.* AGV), logistic control algorithms, etc.

Today all ports try to reduce diesel engine related emissions (nitric oxides particulate matter) by specifying conformity with international directives for non-road mobile machinery. But for new concessions, stringent sustainability requirements are becoming state-of-the-art. When fulfilling such requirements and supporting sustainability, the developments in hybrid drives (serial or parallel) and even full battery-driven equipment are of interest. The first prototypes of battery-powered or hybrid-driven tractors are already running, but so far the high investment costs and

Fig. 4.8 Different types of transportation equipment (increasing sustainability)

uncertain operating costs block a wide-spread application. On top of that, there is the influence of the driver.

In this respect the application of automated equipment, such as diesel-electric or battery-driven AGVs, is a major improvement with regard to fuel-consumption and emissions (see Figure 4.9). The automatic control of AGV power trains makes it possible to run an AGV smoothly and efficient as they are driven with controllable speeds and accelerations (see Dobner (2002)). Manually operated transport systems such as ShCs or TTs accelerate and drive at full throttle in most of the cases just because its men's nature ("toys for boys"). From more than ten years of experience it was learned that automated drives lead to less component wear (tires, engines, breaks, etc.) and consequently to a longer equipment lifetime reducing the terminal's annual maintenance and amortization costs. This is a real contribution to sustainability.

4.5 Selection of Sustainable Stack Handling Systems

When selecting a stacking concept, it must be clearly defined which objectives are considered in the selection process. Traditionally, the terminal operator must balance three major objects:

- *Service driven*: the best response times for customers (shipping lines, trucking). This goal is often valid for dedicated terminals.

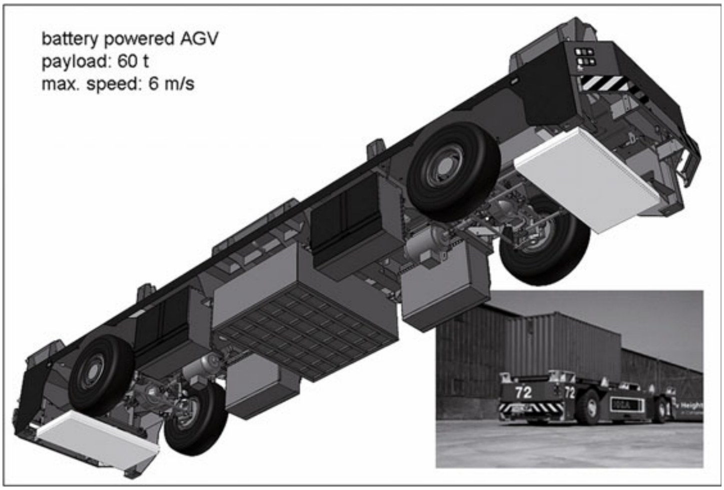


Fig. 4.9 Battery powered AGV: design concept and prototype (May 2009)

- *Cost driven*: the lowest cost per handled container. Especially privately owned multi-user terminals cope for this objective.
- *Volume driven*: the largest flows of containers to be processed through the terminal yard. Port authorities, maximizing the revenue per hectare may support this goal.

And now sustainability should be incorporated as well. However, for this objective all actors involved must focus on such a combined effort to realize sustainable port operation. Figure 4.10 shows the dilemma for the operator: in which direction should be optimized?

Increasingly, port authorities are translating trends and demands from the society into eco-efficient directives for tenants/terminal operators and transportation companies. If the dominant goal is sustainability, then a number of (measurable) indicators must be defined. Such eco-indicators can be the:

- amount of energy per container visit (container passage through the terminal),
- ratio of used energy types (fossil, renewable, nuclear),
- area utilization per 1,000 TEU yearly throughput,
- area utilization as stack capacity in TEU per hectare (only determined by the stacking design concept),
- material spoilage ranging from lubrication materials up to the lifetime of capital investments (a longer lifetime is more eco-efficient),
- recycling rate,
- environmental impact factor (horizon pollution, ecological deterioration, water spill, etc.).

Today's engineering tools allow a proper estimation of all such indicators already in the conceptual design stage. With dynamic simulations it is possible to verify

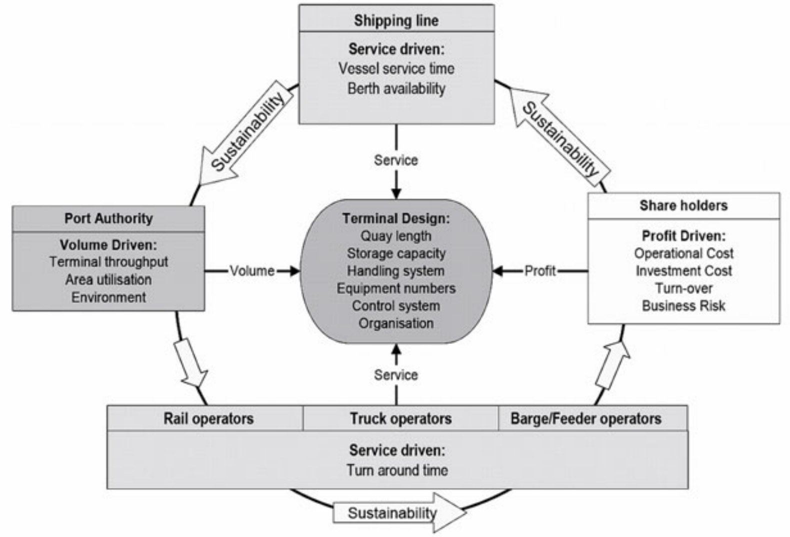


Fig. 4.10 Terminal operators dilemma: service, volume, profit or sustainability

service levels and performances (under realistic stochastic operations conditions), traveled distances, etc. For instance in an in-house study it was calculated that in a front-end interchange concept the RMGs used 4.5–5 kWh per container handling cycle (depending on weather conditions). In an equal case study an analysis was made about the required vehicle driving distances, clearly showing the advantages of a front-end interchange concept (see Figures 4.11 and 4.12).

Such tools can also be used for control strategies to avoid unfavorable energy consumption peaks that will occur when a number of cranes start accelerating at the time (gantry ward/main hoist). Peaks in power demand are often very expensive and not very sustainable (too much investment for over dimensioned supra- and infrastructure). Thus, such smart control algorithms will pay-off in rather short time and can be evaluated in advance with dynamic simulation tools (see Saanen (2004)).

Another interesting topic for a designer of a stack handling system is the question, how many transportation vehicles on the waterside and stacking cranes would be necessary for the throughput requirement between quay crane and stack. In this connection, referring to the number and average productivity of the available quay cranes only is a usual mistake. A dynamic simulation will help to select the required amount of equipment, making a trade-off between service (looking for always sufficient equipment, regardless of some occasional waiting) and sustainability when striving for high utilization and low energy waste (less service).

In addition to the above mentioned large variety of operational parameters, the selection of a stacking concept can be influenced by policies for future developments such as the potential for expandability or possibilities for automation in order to better cost-control and to optimize terminal logistics with computer-based forecasting and last-minute planning tools (see Rijsenbrij and Wieschemann (2004)).

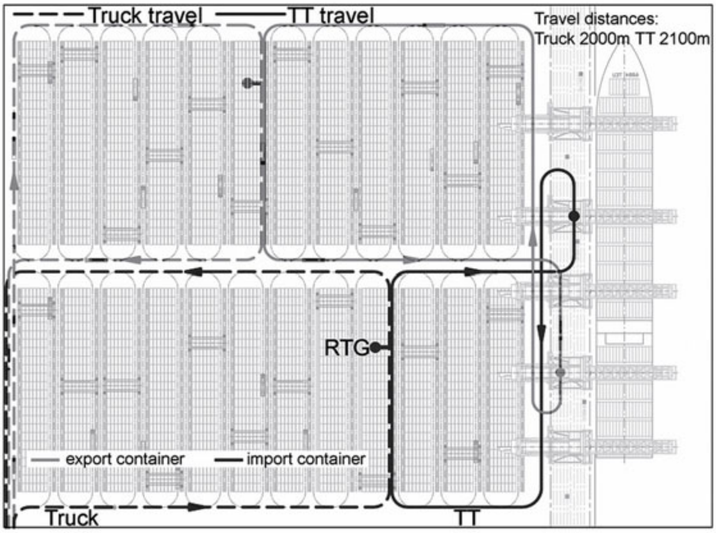


Fig. 4.11 Driving distances for parallel-interchange

However, in most cases the final selection will be based on overall cost and only recently port authorities and/or regional/national authorities require measures to assure some eco-friendly characteristics.

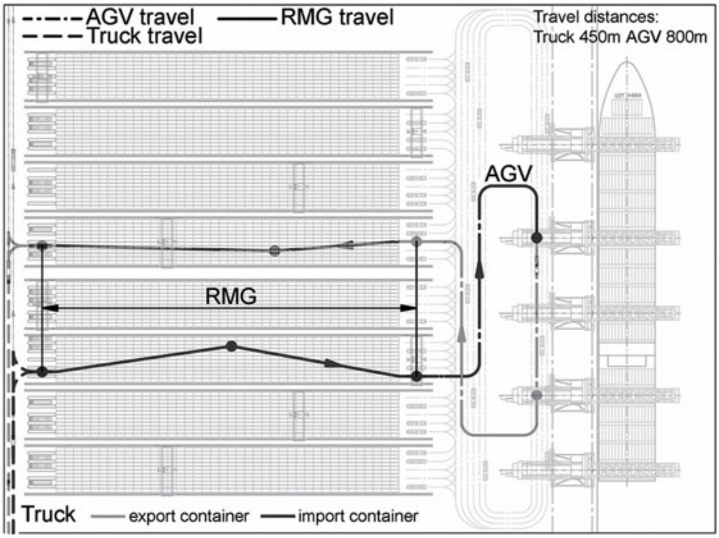


Fig. 4.12 Driving distances for front-end interchange

Up to now the majority of economic evaluations is based on low investment cost and "reasonable" operating costs without any inclusion of costs for the environmental impact or future demolition costs. Recently there is coming up more interest for a total life cycle cost analysis and in such an analysis the following topics should be addressed:

- equipment costs (depreciation, interest, energy demand, maintenance, etc.)
- personnel costs
- area demand and area utilization
- installed capacity vs. utilized capacity
- required performance (average handling capacity, peak capacity, service times)
- built-in potential for future expansion
- technological complexity (risk) and probability of revenue losses
- break-down potential (installed redundancy, special facilities, *M*ean *T*ime *B*etween *F*ailures (MTBF), *M*ean *T*ime *T*o *R*epair (MTTR)
- environmental impact costs, based on a sustainability rating
- preparation and demolition costs

It is recommended to compare the total life cycle cost per stacking concept alternative with the belonging service level, flexibility and sustainability per alternative. There is a tendency to consider the NPV-method (*N*et *P*resent *V*alue) as the leading instrument for decision-making. However, it is more realistic to consider the initial investment, the expected yearly operating costs and the materialized level of sustainability, as separate indicators as well.

It will really take a change in mind-set for (financial) management to incorporate sustainability in their decision making process. Over the last years, many investment decisions were made upon low investment and the avoidance of business risks. It will take quite some years before sustainability will dominate the decision making.

4.6 Conclusion

Terminal operators are increasingly confronted with a demand for more sustainability, both in their terminal design and in their daily operation. As explained, sustainability needs to be defined and quantified and then some objectives should be stated in a program of requirements for terminal handling system designs.

Over the last 15 years new handling systems have been developed and the introduction of (partly) automation has caused some changes in terminal handling concepts, including the potential for sustainability defined as: "Meeting the needs of the present without compromising the ability of future generations to meet their own needs."

A change from stacking concepts in which "the container comes to the crane" (parallel-interchange) towards crane stacking concepts where "the crane travels to the container" (front-end-interchange) will largely contribute to sustainability. Driving distances at the terminal with diesel-powered rubber-tyred equipment are substantially reduced and the use of renewable (mostly electric) energy can be increased. Also, in the design of pavement, buildings, information networks, etc. more sustainable design concepts can be applied.

Many terminal operators are reluctant to invest in sustainable design-concepts. The benefits are for the neighboring environment and the society as a whole. This is very impersonal and difficult to quantify in the annual business reports. Moreover, the realization of a more sustainable terminal design may deteriorate the terminals competitive position (price levels, directives for customers) and so there is not much enthusiasm.

On the other hand, recent building programs of new terminals have shown that (partly) automated stacking concepts do realize lower life cycle costs and consume less energy per container movement through the terminal (see Dobner (2002)). On top of that there is a tendency to apply electric energy, giving the option to use renewable energy.

So, the awareness about the need for sustainable design is growing, but it will take many years before a sustainable design approach will be fully matured and incorporated in a systems design approach for container terminals.

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Chapter 5
Modeling Techniques in Planning of Terminals: The Quantitative Approach
Ensuring planning becomes reality

Yvo A. Saanen

Abstract
The use of models in the process of planning a container terminal, or optimizing day-to-day operation, as well as to ensure the quality and configuration of the control software at a terminal, has proven to be of great value in practice. Simulation models, as one kind of models are particularly well applicable due to the variable and interdependent nature of process at a container terminal. For the various stages in terminal planning and expansion, various types of models are needed. At the early stages more abstract models are applicable, and in later stages this can lead to very detailed models, capable of answering very detailed questions, such as about ways to control the terminal, and about the exact kinematic specifications of equipment. A crucial part in the process of applying models, is validation – making sure the models are representing reality for the scope of the analysis, as well as accreditation – making sure that the users of the results models provide are actually trusting, and therefore also use them. Finally, we have seen that the lifespan of simulation models, in particular, has been extended from early planning questions to final commissioning of control software and day-to-day operation, where models serve as a means for answering questions in a quantitative way, as well as project memory.

5.1 Introduction

Terminal planning involves high capital investments, and therefore needs to be conducted in a systematic, thorough manner. In order to oversee the planning tasks and all available options, allow for a holistic design, and ensure that all system components – equipment, labor, IT, and layout – are well aligned. This necessity increases

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with the growth of terminal complexity due to scale, and more advanced technology in the form of automated processes, which are both administrative as well as physical.

This Handbook contribution is about the application of advanced models to support the terminal planning process. The aim is to realize the terminals as planned, also with regard to performance. Recent experiences – APM Terminals Portsmouth, DPWorld Antwerp Gateway – have taught us that such is feasible. Both terminals prove to be high performing, despite (or better said: due to) the advanced technology deployed.

The contribution's outline is as follows. First we will deal with the question about why to apply models, followed (see Section 5.2) by when it is appropriate and useful (see Section 5.3). In the Sections 5.3.1 to 5.3.4, we discuss the various steps in the terminal planning process and the type of models that we typically apply. We also mention some other types of application, such as how to optimize day-to-day operation (see Section 5.3.5). Subsequently we go through a number of guidelines to be observed when using a modeling approach (see Section 5.4) and finally, we end the chapter with concluding remarks.

5.2 A Modeling Approach – Why?

Before discussing the details of modeling in the context of container terminal design, we first need to ask ourselves why modeling? According to Holbaek-Hanssen et al (1975) *…it is necessary to have suitable tools for system description in order to be able to understand, design implement or control complex systems. By writing a system description, the inquirer forces himself to consider relevant aspects of a system, and a system description language should be so constructed that it assists him in this process. By writing a description, the inquirer makes it possible to convey his conception of the system to other people. Thereby he may contribute to their knowledge, and make it possible for them to correct his views and to improve his understanding.*

Basically, a simulation-based modeling approach, also addressed as a simulation approach (Rozenblit (2003)), is a *problem-solving* driven approach using models to define the problem more clearly (avoiding to solve the wrong problem), to prototype and assess various ways of solving the problem in a *quantitative* way. The essence of simulation is to make a *valid* model of the (future) reality within the scope of the objectives. Validity is determined by the *scope* of the analysis. For specific questions, a rather abstract, aggregated model can be well suited, whereas for other questions a detailed model may be required. It is the task of the modeler to capture the real system in such a way that the model is able to answer in a valid way. The purposes of the use of models are the following (Booch et al (1998), p. 13):

- To capture and precisely state requirements and domain knowledge so that all stakeholders may understand and agree upon them. The interesting thing here is the assumption that all stakeholders could possibly understand or even agree on the models. In practice this is not always possible, because modeling always contains an element of subjectivity, albeit the modeler's way of representing and depicting a real thing.

- To think about the design of the system. In principal a model is a simplified representation of reality or future-reality that enables an analyst, a designer or a constructor to investigate the subject in a cost-efficient way. Here for instance, performance optimization is one of the key objectives.
- To generate usable work products. Because models can be made in an early stage, they function as source of inspiration for new alternatives, as well as way of analyzing possible consequences of the choices that have been made or are being made.
- To organize, find, retrieve, examine, and edit information about large systems. As systems become more and more automated as well as more complex due to their scale, intelligence etc., the need for tools (*i.e.* models) rises, which enable the stakeholders to define views or aspects of the system, and model them individually as well as coherently.
- To explore multiple solutions economically. Especially if there are hardly any similar systems in existence that can serve as calibration (*i.e.* the best practice), the need arises for models as means for analyzing and evaluating alternatives. With those models, we are able to provide insight into the consequences of possible alternatives, before implementing them in reality.
- In order to be convincing, the insight a model provide must be of a high quality. Especially in this area, where the processes are of a complex nature (dynamic, uncertain, mutually dependent), where conventional systems are about to be replaced with new, automated systems, and where the decision-makers tend to be very risk-averse, it is a challenge to obtain the required level of quality.

Quality aspects are the validity of the insight based on the results from analyzes and their resemblance with reality, and the credibility of the insight: as important and indicative for the degree to which the results will be applied in the decision-making. The situation is even more complicated when completely new concepts are introduced, because validation cannot take place by comparing the results with current practice.

In the light of the design of new (automated) container terminals, in which new technology is typically applied, the following key objectives of a modeling approach may be emphasized:

- Enclosing the (new) specific properties of processes at a maritime automated container terminal into the modeling environment that we use to gain insight from and to perform the analyzes.
- Ensuring that the insight we provide by applying the models is reliable and valid. How can we validate results when we do not have similar examples that are already operational?

Although simulation-based modeling approaches and resulting models of processes and sub-systems are increasingly used at container terminals, it is not as commonly applied as it is, for example in the automotive industry, where no investment above hundred fifty thousand euro is made without thorough prove by means of simulation. This is not strange at all when knowing that the rule of thumb is that for every euro spent on simulation, ten are saved.

In addition, a modeling approach is only common in the early stages of the design process. In the later stages, *i.e.* when the terminal is being built, the emphasis on using models is (much) less in our experience, although in recent examples we have experienced that the continued application of models during implementation can be highly beneficial. Models provide a "project memory" during the entire duration of the project, they can give answers to questions at various levels of detail at any time, and are able to recapture reasons for earlier decisions.

That being said, the problem setting at container terminals is one that has triggered many modeling efforts to tackle specific problems at terminals. A recent overview of Stahlbock and Voß (2008) shows many model supported approaches in the field of operations research focusing in particular the optimization of day-to-day operation – *e.g.* berth planning, crane allocation, stack planning, equipment dispatching, and equipment routing – and find better ways of organizing these (Stahlbock and Voß (2008)).

5.3 When to Apply Models?

The design-engineering process of a new container terminal, terminal extension, or conversion can typically be divided into four types of activities (Saanen et al (2000)):[1]

1. Conceptual (or Functional) Design
2. Technical Design
3. Implementation and Realization
4. Commissioning and Operation

These four activities are not necessarily executed sequentially, in practice there will probably be significant overlap and iterative feedback loops. Nevertheless, the type of problems that have to be solved differs between the phases. The differences can be categorized into three categories:

- contents of problems to be solved (aggregation level, type of questions)
- information available (problem space, solution space)
- type of people involved (from managers to technical and operational people)

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[1] In system design literature (*e.g.* Roozenburg and Eekels (1998), Pahl and Beitz (1999)) the same activities are divided over different phases, but can all be covered by the following activities.

In the next sections, we will discuss various key steps in the design-engineering process of a container terminal where models can (and should) be applied. The following steps will be discussed:

- determine the dimensions of the terminal (*e.g.* quay length, stack size)
- determine the type of handling system (equipment + operation + layout)
- specification and testing of the *T*erminal *O*perating *S*ystem (TOS)
- optimization of the operation after go-live

First, we elaborate on the typical modeling cycle, which is applied in all these steps.

5.3.1 The Modeling Cycle

Models can be aimed at decision-support for various questions. In the consecutive sections we will discuss the key topics for modeling in the context of container terminals. In general, a modeling project exists of the following steps:

- analysis of the problem or situation
- specification of the problem and development of the model
- validation of the model
- experimentation with the model base configuration or actual situation
- analysis of the actual situation: definition of bottlenecks
- design of alternative solutions
- modeling of alternative solutions
- experimentation with the alternative solutions
- analysis of the results and drawing conclusions, which leads to the decisions regarding the design

This process is iterative in principle, until one has reached a satisfying solution, which meets the design criteria, or improvement objectives. The aforementioned cyclic approach can be applied in each of the activities described below, however by using different models.

5.3.2 Dimensioning the Container Terminal

In a design process of a container terminal, a typical first step is to determine the main dimensions[2] of the terminal, given the objectives with regard to volume, cargo mix, service levels, and taking the characteristics of the cargo flow (type of carriers, type of cargo, transhipment ratio, modal split, seasonal variation, peak factors, dwell times, etc.) that goes through the terminal as starting point. As these characteristics

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[2] Quay length, terminal depth, total storage area.

are usually surrounded with quite some uncertainty, it is eminent importance to analyze the consequences of variations by means of sensitivity analysis.
In order to arrive at the terminal's dimensions, which fit service level objectives and assumed cargo flow characteristics, we need to analyze the service level (vessel service time, gross berth productivities, and crane density on vessels) under varying terminal configurations (quay length, number of quay cranes, gross quay crane productivity). For this purpose, the principal focus of investigation is first the terminal quayside, and a typical type of model is being applied, called a berth simulation (see Figure 5.2). This type of model is referred to in many studies (*e.g.* Henesey et al (2004)).

Typically, per configuration, one year of operation is simulated, creating a picture of the service over the year. During the year, the variation in storage requirements (seasonal effects, peaks during the peak and even hourly peaks due to large discharge calls), the variation in berth occupancy (due to vessel delays, and variation in the call size), and the occupation of quay cranes can be observed (see Figure 5.1), giving a rich picture of the service the terminal provides.

For every distinct phase in the development trajectory of the terminal – assuming that the terminal is built in phases, aligned with the expected volume development – this experiment is repeated, determining a lean and feasible development path for the quay length, the size of the storage area, the number of quay cranes (see Figure 5.1), and the peak loads – for quayside and landside – that the terminal needs to be able to handle.

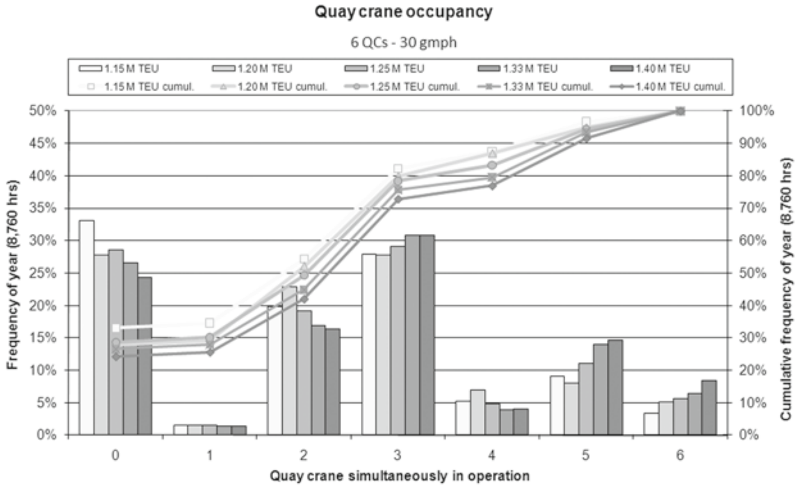


Fig. 5.1 Example of the quay crane utilization distribution over a year

By applying a modeling approach here, it replaces an approach where merely rules of thumb (TEU / m quay for instance) are used. Notwithstanding the fact that these bench mark numbers remain relevant and useful, a modeling approach allows for consideration of the dynamics in the system, such as the arrival time of vessels, as well as the impact of various variables (type of ships, call sizes, crane densities, and crane productivity) in relation to one another. Furthermore, it allows for easy sensitivity analysis of factors such as the gross vessel productivity, the duration of berthing and un-berthing, possible tidal variations, etc.

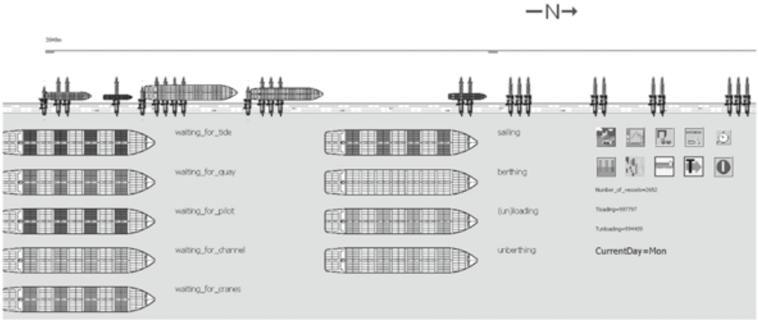


Fig. 5.2 Screenshot from the berth simulation model (Trafalquar)

The simulation model we have created to support this process, is called *Trafalquar* (Saanen (2009a)), which stands for traffic analysis of quay, rail and road. Besides the elements mentioned above, it contains berth assignment rules ("where to berth a vessel?"), and crane assignment rules ("how many cranes on which vessel?"). The latter, in relation to the stowage of the vessel are very much determining how cranes are being deployed. In many cases, it appears that starting with high crane densities does not per se lead to shorter vessel turn times, as the longest hook – the area in the vessel that must be handled by a single crane – determines the vessel turn time.

As an important input for the next step (determination of the handling system), the model creates a picture of the operational variation (including the peaks) in handling (quayside, but also rail side and truck side). These peaks are important to determine how much equipment is required to supply the quay cranes with enough boxes during peak circumstances. Based on the outcome, decisions can be made concerning the quay length, the number of quay cranes, the gross productivity that quay have to achieve in order to accommodate a certain terminal throughput, the requirements for storage capacity (see Figure 5.3), and the peak handling conditions.

5.3.3 Handling System Design

When the outer boundaries are set, one can dive into the more detailed design of the facility. This second step is more comprehensive, in the sense that there are many variables involved, however less uncertainty is typically associated with these variables. The objective of the handling system design is to arrive at a layout, type

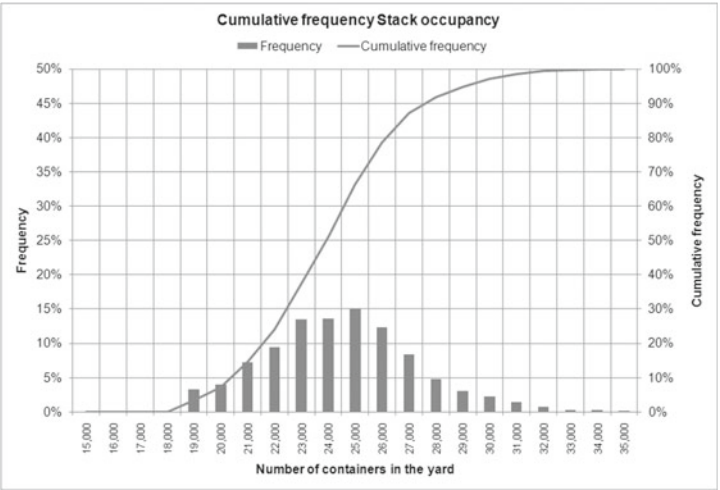


Fig. 5.3 Example of a storage demand distribution over a year

of equipment for the various operations (*e.g.* think of the number of trucks and *R*ubber-*T*yred *G*antry (RTG) cranes, the number of rail cranes, the number of gate lanes, and so forth) as well as a logistic concept, which includes the way containers are handled through the terminal, where they are stored (stacking strategy) and by which equipment.

As more and more tasks are handled by computers, the logistic concept, which is basically the way a terminal is operated and controlled, becomes more important. Especially in (semi-)automated terminals, the terminal relies on its logistic control concept as laid down in the TOS. But also at manually operated terminals, the emphasis is put on efficient operation – for instance the implementation of truck or straddle carrier pooling. In close relation, the TOS should be considered, as only a TOS that has been configured for a specific operation will create a performing operation.

Also the availability of space is one of the factors influencing the handling system. As different handling systems (*e.g.* straddle carriers, RTGs + *T*ractor-*T*railers (TTs), wheeled operation, *R*ail-*M*ounted *G*antries (RMGs) with TTs, *A*utomated *G*uided *V*ehicles (AGVs) or shuttle carriers) have different stacking densities and requirements for horizontal transportation, the throughput ability of a defined yard area varies from ca. 240 TEU / ha for wheeled operation to ca. 1,400 TEU / ha for a 1-over-5 ASC system.

Finally, the selection of a handling system is determined by the peak handling rates (see Figure 5.4), that need to be delivered in order to meet the service level demands resulting from simultaneous peaks at quayside and landside (see Section 10.3). There are terminals that have three peak operations per week, and little or nothing during the rest of the week. There are also terminals that have almost continuous operation, with relatively small variations between average and peak. Not

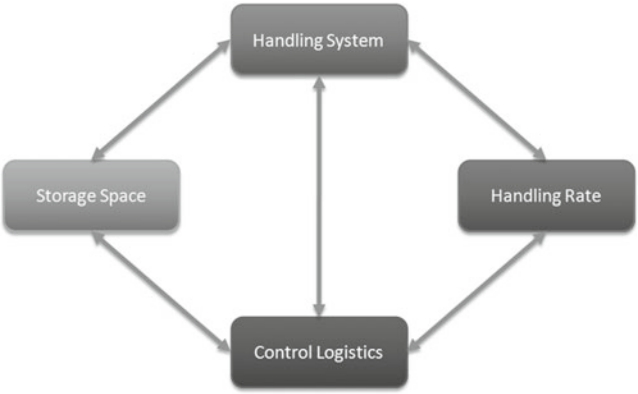


Fig. 5.4 Interdependencies in terminal design

only the pattern of operation, also the required speed of operation determines what kind of handling system is most appropriate. For instance, based on our experience we can say that straddle carrier operation are flexible, high speed, and low density, whereas RTG + TT operation are middle-to-high density, less flexible, and less performing on a machine by machine basis.

Therefore, when considering a handling system, the logistic concept (implemented within TOS), the available space, and the required handling rate have to be considered on a holistic point of view in order to avoid sub-optimization in a particular area, since the four variables are clearly intertwined (see Figure 5.4). A (simulation-based) modeling approach lends itself very well for an integrated approach, in case the processes on the terminal are well represented in the model. Modeling equipment is the least complicated part here, as equipment kinematics (speed, acceleration, deceleration, dead times, load dependency) are typically well defined. It is more difficult to model the drivers of the machines, who may behave quite differently. Skill levels, motivation, safety provisions, and training highly impact their productivity. Also their interaction on the terminal, especially in high-density operation with much traffic, may vary from case to case. To illustrate the importance of modeling this correctly one only needs to look at the technical capabilities of an RTG for example (easily able to handle 20–25 moves per hour, and its realized performance in practice, typically less than 12 moves per hour). Similar effects can be observed with TTs and even with straddle carriers, producing respectively less than 4 and less than 8 moves per hour, where simple 'distance/speed-calculations' would lead to twice those numbers.

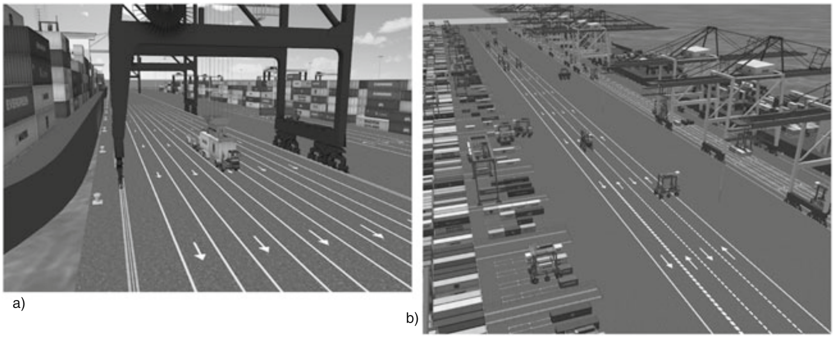
Not only the driver's impact on equipment productivity, also the logistic concept – in terms of stacking strategy, equipment deployment and dispatching – is of a large influence. In many cases equipment is waiting for each other – trucks queuing in the yard and at the quay crane, and yard machines waiting for trucks to arrive – as well as machines have not been allocated by a single job. This may seem to be easily solvable, but so far no breakthroughs have been achieved, especially not from a holistic perspective, optimizing the operation in an integrated way. In order to reflect these imperfections, the TOS also needs to be modeled to a sufficient level. Aspects as vessel stowage (where containers are placed inside the vessel), loading sequence (in which sequence containers are discharged from and loaded onto the vessel), container characteristics (like service, 'Port of Discharge', weight, length and type), grounding rules (where containers can be placed in the yard, such that driving distances, and unproductive work are minimized), and dispatching rules (which equipment unit should do which move) all have a high impact on productivity. If the modeling is not performed correctly, one can easily overestimate a system's performance by 50%.

Moreover, it typically means that by improving the way a terminal is operated, more can be done with less, which can be shown in a quantitative way using a modeling approach. Recent studies have shown opportunities to reduce cost and increase service levels by 20% and 15% respectively, and *at the same time*!

The model we use for these kinds of exercises is called *T*IME*SQ*UARE (TSQ), which models all processes inside the terminal to a detailed level. TSQ not only contains a detailed model of the equipment, and its drivers (or control software in case of automated equipment) but also of the logistic concept (and therefore the TOS). The *validation* of such models is an extensive process, consisting of time and motion studies, analysis of driver's behavior, analysis of the TOS and its configured rules, and interviews with the terminal's staff to get the tangible but not less important behaviors specified. Although validation is necessary for every model built for a terminal, a model with a well-defined architecture contains components that can be re-used between models. This saves time and effort when building and validating a new model.

Not only validation is critical, also accreditation of a model is essential for achieving full use out of a modeling approach. In some cases valid models are still not trusted (accredited) by the decision-makers, and therefore may lead to a diminishing the impact of the results. Even more dangerous is the use of invalid but accredited models: this means decision-makers trust the outcome, although they should not! This sometimes happens when the 3-dimensional visualization that comes with the model (being a powerful support tool when doing validation) is too convincing (see Figure 5.5). From the visualization not only the movements of equipment should become apparent, also their interaction (especially at crossings) as well as the yard strategy (location of containers, way of stacking, shuffling) can be observed. Therefore, statistical validation based on the outcome of the model is at least as important as expert validation, for which the visualization is typically used. Models today can be developed in such a way that the accuracy with which they represent reality is very high, leading to deviations from real results limited to +/- 5%.

What are typical results of models in this step of the terminal planning process? The most obvious is the amount of equipment (dependent on its kinematic specifications, see for instance Figure 5.6 in which the impact of a yard crane's acceleration is shown on the achievable productivity of the yard crane) required to meet the service level demand, as we discussed earlier. Also the "optimal" yard layout can be



a)

b)

Fig. 5.5 Two examples of 3-dimensional visualization of models: a) twin lift operation of quay crane using TTs for horizontal transport; b) automated RMG operations combined with shuttle carriers

determined in an iterative way, comparing the effect of changes in the arrangement of yard blocks, roadways and exchange points between equipment (see Figure 5.7). Furthermore, the utilization of equipment and its energy consumption and driving distances can be determined, which is subsequently input into financial analyzes. In addition, optional control strategies of the envisaged logistic concept (*e.g.* pooling, stacking strategies, and dual cycling) can be compared.

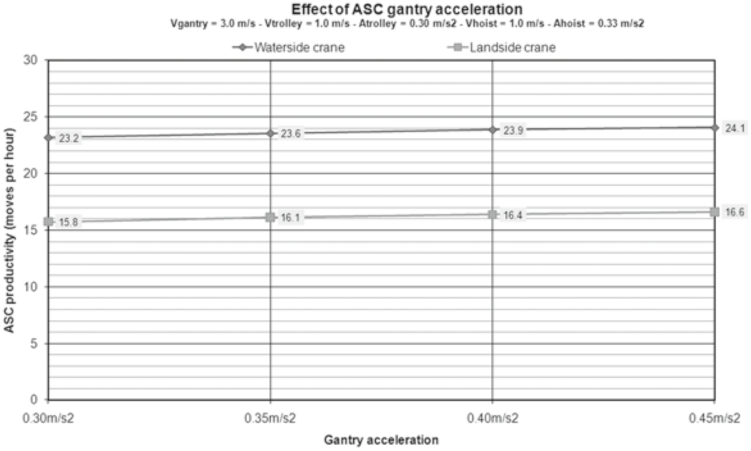


Fig. 5.6 Result from a comparison of kinematic specifications of an RMG (Saanen (2004))

Finally, the impact of changes of external factors (for instance the percentage of recombinations – changes to container destination or vessel after arrival at the terminal, the accuracy and timeliness of loading information, or simply the percentage transhipment or dwell time) can be analyzed. The latter we address as sensitivity analysis, which is very important in case of high uncertainty (‘Greenfield’ terminals) to obtain a terminal design that is robust to changed assumptions.

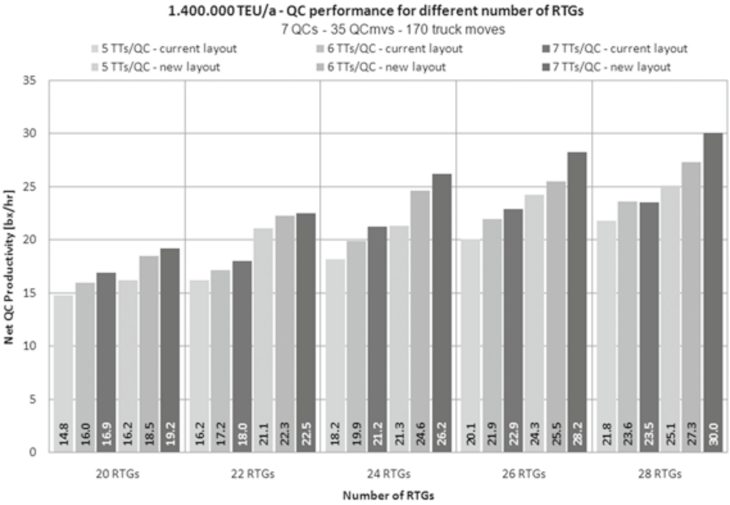


Fig. 5.7 Results comparing the effect of two different layouts

5.3.4 Design of the Logistic Concept

We already argued about the importance of the logistic concept and the way a terminal is controlled (see Section 5.3.3). In practice, this is reflected by the TOS and its users. As it plays a central role in terminal operation (see, *e.g.* Agerschou (2004)), sufficient attention should also be given during the terminal planning process.

As shipping lines are requesting higher service levels, terminal systems need to be designed striving for various – mostly contra dictionary – objectives. Quay crane productivity has to go up, stack density has to increase, operating costs have to go down, and the landside service times have to be shortened. The TOS brings it all together in the form of allocations of space and dispatching decisions for all equipment. In case the business rules and parameter settings are not well configured in the TOS, it may result in major (20%–50%) performance losses compared to the design values.

In order to create handling systems that comply with those requirements, the use of (simulation-based) modeling as problem solving approach has proved to be beneficial to separate good from bad solutions, to prioritize functionalities in the TOS, since not all features can always be implemented, and – last but not least – create a relatively inexpensive and safe trial and error environment for both prototyping and testing new solutions for hardware and software.

Thus, a simulation-based modeling approach is applied here in a different way, as the models provide a test bed with which the real software can be tested and tweaked (long) before going live (Auinger et al (1999), Mueller (2001)). This approach is also termed as *emulation*. Compared to the previous stages of the terminal planning process, the real software is in the loop (see Figure 5.8), the emulation models provide the representation of the physical reality (equipment, drivers, clerks in the operation, and external systems). Important aspects in this step are the high granularity of the models, and their completeness. Since software testing should not only cover the "good weather" cases but also exceptions, the models need to comprehend these events, requiring extensive modeling.

But not only for test purposes, modeling by means of emulation models is useful, it also separates feasible solutions from non-feasible ones; it assesses the contribution of solutions to the overall goals, always putting the entire system performance – rather than the individual performance of components – as key indicator. Moreover, it provides an environment where one can evaluate under varying, but manageable, conditions, *e.g.* busy and quiet operation, breakdowns, and so forth. In the end, this will result in less start up problems, solutions that are better thought through, increased software robustness, all leading to a reduction of risk.

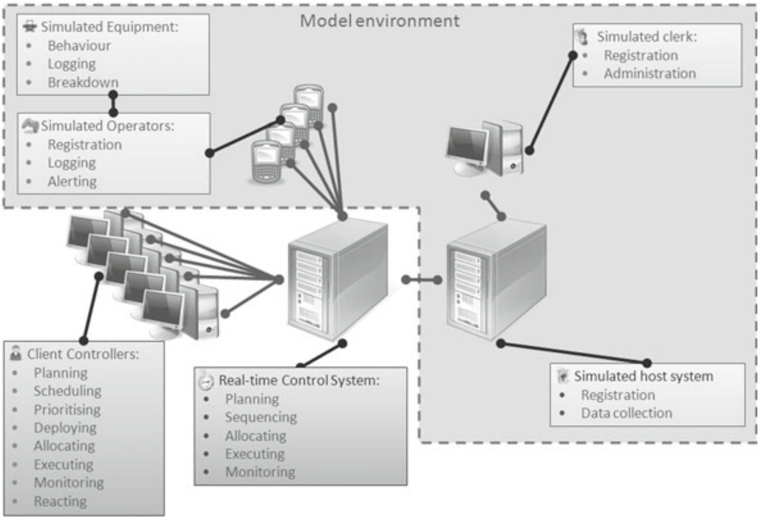


Fig. 5.8 System architecture with real TOS tested in a model environment consisting of the physical reality

5.3.5 Optimize Day-to-Day Operation

Terminals are dynamic systems, with a high degree of interaction with their environment, and limited influence on the external "world". Every day the operation is different from that of the day before. Still, it is worthwhile to explore the possibilities of using models to improve day-to-day operation. While simulation models are becoming more comprehensive, being able to capture real operational procedures, to handle real operational data, to depict processes at the level of individual container moves around the terminal, and to represent decision-making around grounding containers based on the container's profile, we have experienced that their application is beneficial for analyzing past operation, and use them as test bed for improvement measures. The following aspects of operation can be analyzed:

- Manning and equipment deployment given a certain operation at quay, rail, gate, and housekeeping.
- Strategies and patterns of strategies for yard operation in order to increase yard density, and reduce travel distance and false moves (shuffles).
- Decisions concerning the in advance preparation of the yard (so-called housekeeping).
- Changes regarding operational procedures, such as equipment pooling, sharing part of the equipment, real-time re-allocation of equipment, and sizing the gangs.

The outcome of these analyzes can be fed back into the TOS, and into the minds of the managers, planners, dispatchers, and operators running the terminal. It can overcome the often contra dictionary perceptions about the bottlenecks in the current operation, and prioritize improvement measures. By using real data, and using real, past operation, the value of these exercises heavily increases, because it becomes much easier to translate the result back into the consequences for coming operation. Examples of recent findings – see Figure 5.9 in which the effect of the yard strategy on the net quay crane productivity is shown for two different yard strategies: the existing strategy "LZ/DZ strategy" and an alternative strategy "random stacking strategy" – comprise the effect of equipment pooling (15% increase of equipment productivity and therefore a potential of reducing operating costs), and the effect of an improved RTG assignment and yard grounding strategy (20% less equipment is required on average, whereby the productivity level remains the same).

The essence of arriving at models that can accomplish this added value is a good understanding of the operation, including the rules in the TOS. An alternative to overcome cumbersome modeling of TOS functionality is to link the simulation environment directly to the TOS, as has been discussed within the framework of *emulation* (see Section 5.3.4). By doing so, the TOS can be configured much faster to accomplish a smooth and efficient operation under various conditions. In our experience, this has led to substantial improvements in operation, by fine tuning TOS parameters.

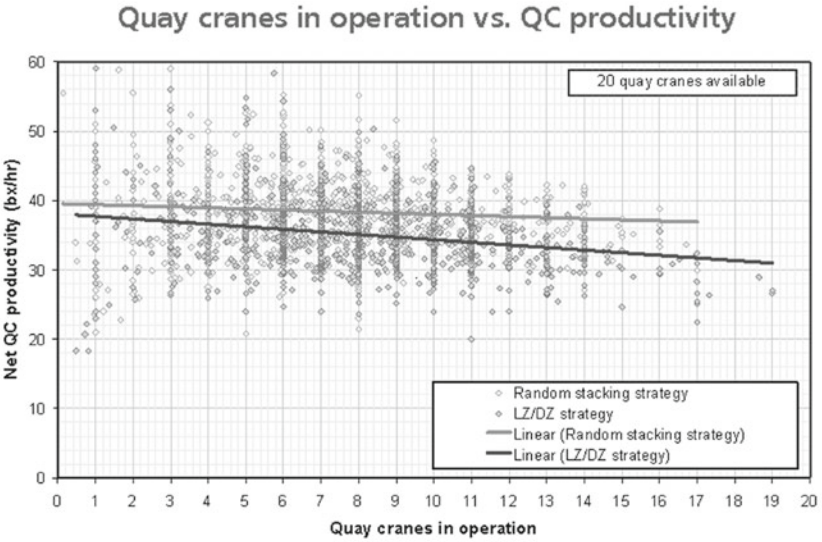


Fig. 5.9 Example of a comparison of 6 weeks operation with two strategies

5.4 How to Apply a Modeling Approach (Successfully)?

Before we all start developing models to design and improve our terminal, we should first deal with the modeling approach itself. And to avoid any confusion: modeling requires skills, experience, and tools, just like any other profession or trade. Although there are several tools available on the market, it does not mean that purchasing these leads to high quality analyzes or results. There is a little more to it than that. Therefore, step 1 is to ensure the right modeling team, then to ensure that the right questions are asked, and then to ensure that the modeling environment (the tools) are also adequate to answer these questions.

When these conditions are met, the basis is laid for successfully applying models. Moreover, we would state that it is recommended to deploy models throughout the entire planning process of a terminal, from the initial conceptual design to the detailed design, and even during commissioning and software testing. In addition we suggest the following guidelines (see also Saanen (2004)):

Holistic, but layered view on the terminal processes
We propose to analyze the container terminal from a holistic perspective, taking all processes between the terminal boundaries into consideration. Of course, some processes require more attention than others, but due to many changes, some processes, which may at first seem unimportant, could influence the system as a whole. In order to keep the design process manageable, we also apply different hierarchical abstractions levels in our analyzes and models see for examples the various type of

models already discussed in Section 10.3 – 5.3.4). Depending on the design activity, we focus on a specific terminal process or component.

Object-oriented view on the real world

We propose to use the object-oriented modeling paradigm, which means that the entities that execute actions are leading. The object-oriented modeling paradigm has a number of advantages (see Rumbaugh et al (1999)), which make this way of viewing the world suitable for a terminal design process. When the object-oriented way of modeling is compared with the flow-oriented way of modeling, the advantage appears in the fact that there are many different processes (flows) throughout the terminal depending on internal and external conditions, not known at the time of arrival. However, the actions that can be performed by the entities (equipment, terminal personnel, and customers) are known and defined. These two aspects make it easier to conceptualize a terminal in an object-oriented way, rather than in a flow-oriented way. Moreover, in the case of robotized container terminals, the use of an object-oriented view of reality eases the conceptualization of the control software, because most control software is object-oriented and, therefore the conceptual description is much closer to the implementation in software.

Explicitly taking uncertainty and process variability into account

A dominant property of a container terminal is the lack of deterministic elements, which has already been argued. The influence of external processes is high, the information presented is of a poor quality or missing, and the variation in behavior of terminal processes is relatively high due to unreliable manual operation or equipment failure. In order to create a design that also works in practice, the design has to address the dynamic system behavior of the real system. Therefore, our guideline is to take the variation explicitly into account when modeling and analyzing the system. We prefer this approach above an approach in which the variability is averaged and the outcome is increased with a certain safety margin to cover peaks. Explicitly modeling the variation of process behavior requires more sound knowledge of the range of outcomes of each process, because not only the (estimated) average is required, but also the minimum, maximum and relative frequency of all outcomes. The choice to model the variation in an explicit way has consequences for the solutions that can be applied, especially in the area of optimization and control algorithms (see Stahlbock and Voß (2008)). Usually optimization algorithms (such as the Hungarian algorithm) treat information as certain. Therefore, in order to be able to use these optimization algorithms, continuous re-planning, based on the actual available information, is required. Only then, the information used as input for the optimization can be considered as relatively certain.

Identify impact of manual interventions

At most terminals, many processes are still dependent on human operators. This heavily impacts the outcome of operation (see the example in Figure 5.10), and therefore it should be considered in the modeling process. In the modeling environment there should be room for varying skills, and various unpredictable decision-making. Also the interaction between man and machine at execution and control level is a key issue in a terminal's design.

In Figure 5.10, an example is given of the impact of the operator's experience on the service levels that a terminal can deliver. In this particular case, the terminal start up was planned with (experienced) expat labor, with a step-wise transition to local labor.

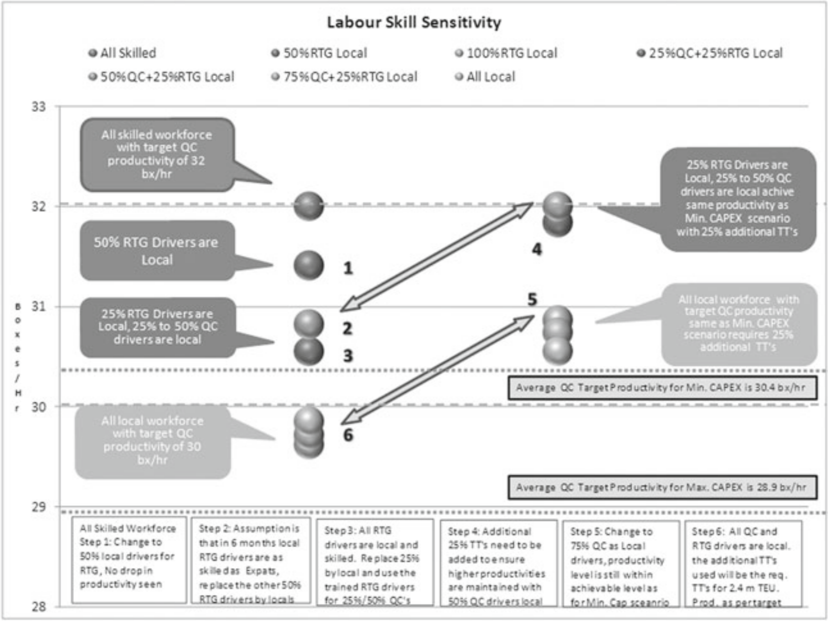


Fig. 5.10 Example of impact of operator skills on quay crane performance (Saanen (2009b))

Base the decisions within the design process on performance measurements In order to understand the behavior of the process that is carried out at a container terminal, adequate measurement criteria (so called *K*ey *P*erformance *I*ndicators, KPIs) have to be developed, because only then can relationships between events or actions and the output of the system be laid. In addition, operational data has to be collected in order to determine whether the criteria have been met. The designers can analyze the processes and define the bottlenecks with actual operational information. Therefore, the performance indication instruments should not be limited to the indicators that measure the performance towards the customer. Earlier cases (*e.g.*, Dobner et al (2002)) have shown that it is better to have too many indicators than to have too few, mainly to create more insight when the system behaves in a different manner than expected.

Moreover, improvements should always be instituted when there is a lack of performance in accordance with the measurement criteria. When these criteria do not converge with both the terminal goals and customer goals, then the criteria have not been well defined. Subsequently, the priority of improvements should be determined based on the potential performance increase of the improvement. In the modeling environment, these KPIs should be measured, and presented as a result.

The design process should be an ongoing process in order to keep the terminal up-to-date with continuous changes
The environment of a container terminal is ever-changing. For instance, the handled volume increases, the size of vessels changes, the modal split changes and the labor cost changes; in most design-engineering processes, the design team is dissolved after commissioning. However, in an environment with ongoing changes, the design process should be continued in order to keep the terminal fulfilling it requirements. In the inductive cases, we have learnt that many terminals do not remain up-to-date, which leads to a decreasing service level or a less competitive position because internal and external factors such as labor costs, dwell times, and the vessel call pattern change.

The (re-)design effort might be at a less intensive level after commissioning, however, the evaluation and improvement process should be continued in order to know whether changes are required or improvements can be made. This also means that a model environment, meant to support questions in relation to the changing terminal environment, should be kept up-to-date; this to avoid long periods of model updates when urgent questions arise.

The architecture of the modeling environment should mirror the system architecture, including the TOS
It is common to model in accordance with the scope and purpose of the analysis for which the simulation is used. Often, this results in models that are more or less different from the system that will be implemented in reality in terms of structure and processes. That is not a problem in itself; it can even reduce costs of model development, because the representation of reality in the model was easier to realize and still valid for the purpose for which the model was developed. However, it does not contribute to the reusability of models within a design project where the same system components are redesigned multiple times. Nor does it support the use of the same models throughout an entire design-engineering process, because there are multiple purposes inherent to the various activities in the design process. Finally, yet importantly, creating a model whose architecture is similar to the real system is beneficial during the implementation process, where it can serve as system environment for function and technical testing. Therefore, we propose developing simulation models that have an architecture, which is similar to the real system, both hardware and software.

5.5 Concluding Remarks

Operations at container terminals are highly complex. Automation makes them even more complex. The use of models – enabling especially the representation of dynamic and uncertain real world aspects – is an effective methodology to facilitate terminal planning processes by providing quantitative data to decide upon, and allowing comparison for all kinds of alternatives and ideas in an inexpensive way. As a result, more balanced and leaner terminals are being realized, which also meet the performance objectives in reality.

The type of models that we consider most suitable for container terminal planning – in terms of recognisability, and dealing explicitly with stochastic effects for representing terminal operation – are dynamic simulation models. Optimization tools treating the operation as a deterministic process are difficult to apply, because in real-time the operation differs highly from the planned situation. Therefore, tools that explicitly consider the dynamics of life operation should be favored above others. In addition, most simulation models are also able to represent and visualize container terminal operation.

Applying a related modeling approach makes the decisions concerning the investment in the quay and quay cranes, the choice of handling system, and the configuration of a terminal's control system better founded, better to understand, and more transparent. It enables a terminal operator to reduce the risks of the terminal development and extensions. It also enables a terminal operator to improve the terminal on a continuous basis. Finally, we have seen that it justifies itself as testing and tuning tool when implementing a new TOS.

However, when a system modeling (by means of simulation) is applied, one should make sure that the specific characteristics of operation are validly represented in the model (*validation*), and that the decision-makers have confidence in the models (*accreditation*). Otherwise, the risk of nice pictures over sound results lies just around the corner.

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Chapter 6
Simulation Technology in Planning, Implementation and Operation of Container Terminals

Holger Schütt

Abstract
During the last 50 years simulation technology found its way from technical applications to the logistics. Due to the demand of high productivity and automation as well as increasing vessel sizes, special computer systems for simulation and emulation have been developed for container terminals. Nowadays all change and innovation processes regarding terminal structures and operation may be accompanied by means of simulation and emulation. Although the current worldwide economic crisis entails uncertainty it also provides the opportunity to improve actual planning procedures as well as operations processes. A holistic approach of using means of simulation or emulation in the field of planning, implementation and operation of container terminals is introduced in the following to explain the possible range of application from global to detailed analysis and optimization. In this respect it will be emphasized that the terminal operator himself will be enabled to use these tools without being a simulation specialist.

6.1 Simulation in Logistics

In the last century simulation has found its way into the automotive industry where nearly each investment is verified by simulation means (see, *e.g.* Burges and Mayer (2006)). This approach nowadays becomes more and more accepted in the analysis of logistic processes, especially in the field of container terminals. Examples for terminal simulation are given by Huang et al (2007) as well as Khoshnevis and Asef-Vaziri (2000), an overview about various simulation projects is given by Stahlbock and Voß (2008).

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Whereas the increasing power of computers has solved the performance problems, there still is another challenge to be managed: logisticians normally are not able to handle simulation systems. Therefore, special simulation tools are developed to close this gap between application knowledge and the theory of simulation. Examples are shown by Schütt (2008). The base of such tools which uses terminal operator's vocabulary was published by Boll (1992).

6.2 The Planning Phase of a Container Terminal

As a result of strong competition between the ports and terminals it is essential to reduce cost and to improve the service quality. To satisfy customers' demands, like short lead times and high quality products, it is nowadays necessary to carry out all operations very fast and efficiently. To meet these demands, terminals are looking for new techniques, such as automated transportation systems and automated ways of control. Furthermore, there are many significant industry changes that influence the development of terminals, *e.g.* increasing vessel sizes, space limitations as well as labor agreements and labor costs. These constraints raise the question whether the terminals will optimize operation to increase the throughput of existing terminals or if new facilities will replace or expand existing capabilities. The terminal of the future, in some places, must use new technology to meet these upcoming requirements.

But: the more complex and automated the operation at the container terminal become, the more rises the importance of a high sophisticated IT-system to cope with the new demands. Furthermore, some of the influencing quantities have a random character as *e.g.* arrival times, daily number of boxes, loading and discharging times of vessels, container movement time of cranes, etc.

With the aid of simulation technology it is possible to reproduce the system "container terminal" as a virtual system in order to analyze an existing or planned terminal in detail. As simulation of logistics processes normally uses IT components as means of representation, the real system "container terminal" has to be represented by software models that are executable on related (hardware) components and reproduce terminal processes – including fortuitous events – in an equivalent or adequate way, respectively. Thus, the means of simulation is a powerful tool by which the user can "play through" and subsequently analyze the processes of a terminal in order to get a transparent basis for the decision-making process.

The planning phases of a container terminal may be supported by the means of simulation. For each of these phases, distinct simulation tools have been designed in such a way that users can, even without availing themselves on a software engineer's specialized expertise, 'play through' several scenarios with input parameters chosen by themselves.

As shown in Figure 6.1 various tasks have to be regarded within the planning phase. While in the beginning of the planning (preplanning) the amount of information about the terminal is very small (low level of detail) it increases with time

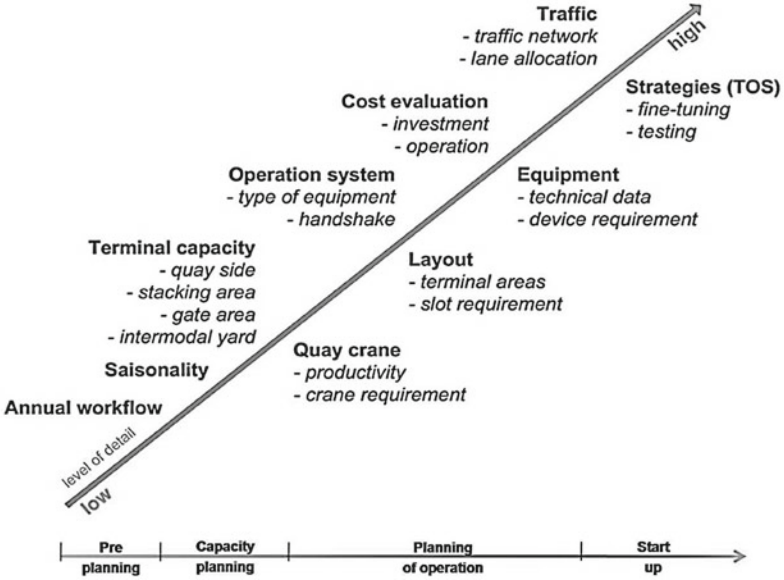

Fig. 6.1 Tasks during the planning phase of container terminal operation

until the implementation of the operation starts at the end of the planning phase. Due to the amount of information available, different simulation tools may be used for the analysis. In the preplanning phase the planner has to think about the annual workflow of the terminal, typically spreadsheets are used in this phase. Knowing more about the seasonality of the container flow and rough planning data about the terminal (area, quay length) a first calculation of the capacity of the terminal may be done. By getting more information about the operations system, the layout and the technical data of the equipment, detailed planning of the productivity and the amount of devices needed may be carried out. At the end of the planning phase and during start up of the terminal the fine-tuning of the strategies can be supported. Examples for such kind of tools supporting these tasks are discussed in the following sections.

6.2.1 Terminal Capacity

The first question while planning a terminal is calculating terminal's capacity. A tool working on the lowest level of detail of available information does not consider the operations system the terminal uses. The capacity of a container terminal is limited by the capacity of the container stacking area and the quay. The latter is limited by its length and the capacity of the *S*hip-*T*o-*S*hore (STS) cranes available. The aim of such a tool is to identify the current bottleneck of a terminal. With this, the user can determine how much throughput a terminal handles with the existing facilities, as well as the maximum possible capacity of a planned terminal, *i.e.* how much throughput does a terminal handle.

Such kind of simulation tool requires a multitude of input data for simulation, *e.g.* information about the yearly throughput which has to be investigated, and its distribution over the year in order to simulate peak times. The number of container slots available is needed as well as the container dwell times regarding individual container types. The tool provides the possibility to develop several vessel types for the quayside definition, to design the quay in any desired configuration and to distribute the STS cranes along the quay. The Figure 6.2 shows a screenshot of a *CA*pacity *P*lanning *T*ool called CAPS (see Boll (2004)). As to be seen terminal's operations system is not regarded in the simulation. Solely the quayside – with waiting and served vessels as well as available and working quay cranes – and the utilization of the stacking yard – shown with pie charts – will be evaluated.

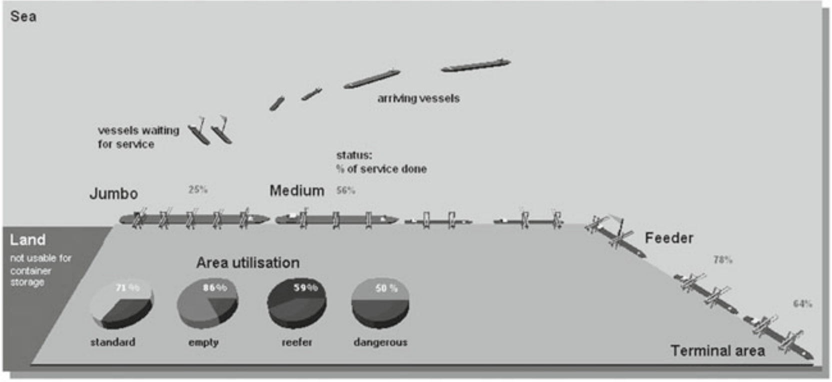

Fig. 6.2 Screenshot of the capacity planning tool CAPS.

After simulation, the tool evaluates the quay as well as the stacking area and provides information about the utilization of the quay and the crane performance. The user is informed, *e.g.* if the quay length fits to handle a definite container volume and how many STS cranes are necessary to serve the arriving vessels. For the area evaluation, the tool ideally distinguishes various area types (*e.g.* areas to stack standard, reefer, dangerous, and empty containers) and it provides an indication of the sufficient number of stacking slots.

The operations system responsible for stacking and transporting the ingoing and outgoing containers is not examined. This is part of a further step of terminal planning going into details.

6.2.2 *Simulation and Analysis of Container Terminal's Operations System*

The simulation of the operations system used supports the user in investigating planning alternatives or stochastically elaborated designs of container terminals. The design comprises the layout and the deployment of equipment. The interdependence of these two factors is a focal point of simulation models at this stage, *i.e.* it investigates which areas are available and which equipment types and operations system should be deployed best.

The evaluation of the simulated container terminal is carried out with regard to economic and technical aspects. The output of the target variables, measured against each other and interpreted, are the cost incurred and the handling volumes achieved. This strategic level covers the planning of new terminals, the expansion of existing ones and changes in organizational structures. Simulation tools applied for this purpose do not track each single container but the behavior of the whole system 'container terminal'.

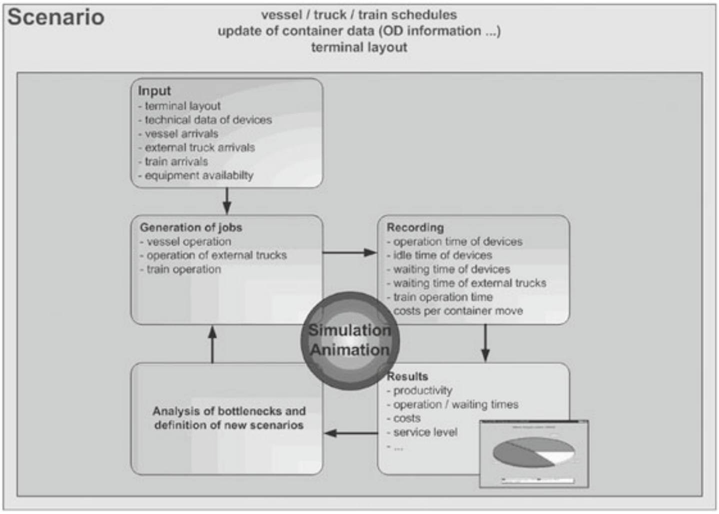

Fig. 6.3 General procedure for simulation of container terminals[1]

With regard to simulation analysis of terminal's operations system a separate module is usually applied for drawing up appropriate simulation scenarios. The scenario module combines all input data needed by the respective simulation tool and builds a frame for each analysis. In this regard, Hartmann (2004) describes how to generate consistent data.

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[1] OD Information: Information about the origin or the planned destination of the container.

The simulation approach shown in 6.3 includes a scenario module and provides the necessary flexibility for taking new concepts of the system interfaces quayside, gate and railway into consideration. After entering the information about the layout of the terminal – typically using a graphical editor –, the amount and technical data of the equipment needed and about the workload at the quayside, the gate and the rail facility, the tool will generate joblists which have to be processed by the simulation. An animation is used to let the user understand what happens within the "black-box simulation". All steps of operation are recorded into a database to get information about waiting and idle times and the productivity achieved. With the results of the simulation the user can calculate the operating costs for each terminal operations system. In the end, a technical and economical evaluation of all analyzed terminal systems will be executed.

In this way the whole terminal operation may be analyzed and optimized. Different operations systems (*e.g.* straddle carriers, *Ra*il-*M*ounted *G*antry (RMG) cranes combined with *A*utomated *G*uided *V*ehicles (AGVs) or shuttle carriers[2], rubber-tyred gantry cranes combined with tractor-trailer units or multi-trailers) may be compared by key production indicators or costs per move. Additionally, the layout may be optimized regarding the size (length, width and height) of the stacking blocks and the traffic control (one way tracks, priority handling). Furthermore, operations strategies (like pooling transport equipment, twin or tandem operation, block allocation) may be analyzed and optimized with tools of this level of detail. The latter delivers valuable insights in organization principles for economic use of terminal resources assuming typical operations cases (see Section 6.3).

6.3 Terminal Start Up and Optimization

Additionally to the tools described, which are mainly used for strategic planning tasks, simulation nowadays is also used to support the day-to-day operation. The basic principle for this is the emulation of the terminal equipment. Emulation is defined as "a model that accepts the same inputs and produces the same outputs as a given system" (see IEEE (1989)). The emulation is directly coupled to the real *T*erminal *O*perating *S*ystem (TOS). With this attributes emulation can be used among others for:

- **Evaluation and optimization of strategies used in the TOS**
  While in typical simulation tools the control strategies for terminal operation are usually modeled within the tool, in the case of emulation the implemented strategies in the real TOS are used. Thus, a more realistic model may be built using this available level of detail. In this way the strategies may be optimized by finding the values of their parameters, which fits best to the container flow and equipment used.

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[2] Straddle carrier with stacking capability of 1-over-1-high.

- **Test bed for the real TOS**
  While the device emulators are reacting in the same manner as the real devices do, the TOS may be tested against a software system instead of the real terminal. Setting up of new releases of the TOS will be much smoother after testing it against software emulators. Furthermore, the tests are more time-, maintenance- and fuel-saving then testing with the real equipment. This test bed may be used by software engineers as well as by terminal operators.

- **Visualization of new terminals**
  Using the 3D-animation component of the emulation tool the planned operation of new terminals as well as new processes at existing terminals may be demonstrated visually. The animation may be used for explaining the changes in operation and to show their benefits.

- **Test bed for acceptance tests of equipment**
  Within the start up phase of a terminal the acceptance test of devices needs trouble free surroundings. Typically this is not given within this start up phase. The failures of neighboring subsystems (STS, horizontal transport, stacking equipment) will disturb the acceptance test. By using the emulators for related subsystems these failures can be omitted and the acceptance test may concentrate on the behavior of the device to be tested.

- **Training purposes of terminal operators**
  With means of emulation the crew of the control tower may be trained without impacts on the real operation. They use the real TOS within their training and use the 3D animation as their “looking out of the window”. The evaluation tool shows the results of their work in terms of key performance indicators, *e.g.* quay crane and vessel productivity or waiting and idle times of the handling equipment. In this way also extreme situations (*e.g.* break down of equipment, delay of vessel arrivals) may be trained without impacts on the real live.

Thus, in contrast to simulation an emulator clones the functionality of the target system. The emulated system receives identical data, works in the same manner and produces identical results like the original system, *i.e.* the emulated system imitates the original one. Considering terminal simulation elaborated models reproduce, among other things, the behavior of devices applied for container handling. These representations may be used as base for drawing up device emulators. Note, however, that emulation typically represents dynamic aspects of the real system in a more detailed way and that an interface between the emulation model and the TOS has to be built, additionally.

The ViTO core system (see Figure 6.4) is based on the simulation tool SCUSY (see Boll (1992)). The layout definition as well as the evaluation and operations database is re-used. While in the case of simulation the information flow and in particular the control strategies are part of the model (considering the level of detail available), the real TOS or the implemented TOS algorithms respectively cover control tasks in the emulation case.

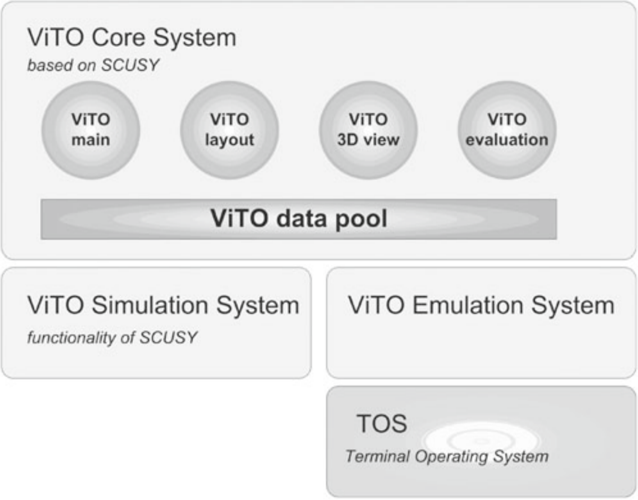

Fig. 6.4 The *Vi*rtual *T*erminal *O*ptimizing system (ViTO) combines the simulation and the emulation (using the TOS as control module) functionality within one tool

The behavior of the equipment has to be simulated in both cases. While in simulation tools typically all devices are included in one model, the ViTO (*Vi*rtual *T*erminal *O*ptimizing) system provides the *D*evice-*e*mulator *Co*mmunication *Net*work (DeCoNet), for details see Kassl et al (2008). In this way the (device) emulators may use different computers in a network. Furthermore, this provides the possibility to use emulators of different suppliers. Thus, a terminal operator may connect the emulators of his device supplier (if available). Especially for the use of complex routing algorithms within the horizontal transport this functionality will be helpful.

Due to the integration of various modules of the simulator SCUSY the emulation system ViTO may be used as an additional function after simulation based terminal planning. Of course the level of detail may require some more data concerning the layout or scenario data, but the main input data may be re-used out of the planning phase. In this way the terminal operator may use an emulation environment in a similar way as he applies tools in the field of simulation. Only the interface to the TOS (called business connector) has to be configured by simulation specialists. In the case of emulation the scenario generator may be substituted by a replay function of historical data, which have been logged during real terminal operation.

In the following figure an example for the acceptance test using emulation technology is shown (see Figure 6.5). While the STSs as well as the stacking cranes are emulated, the real AGV system is coupled to the TOS. In this way the equipment to be tested for acceptance may be checked solely without disturbances of problems with other devices (which have to be expected in this phase).

The TOS uses two interfaces to communicate with the terminal devices: The order interface to send orders to the equipment and the equipment control interface to send and receive status information of the device. In the case of an emulated

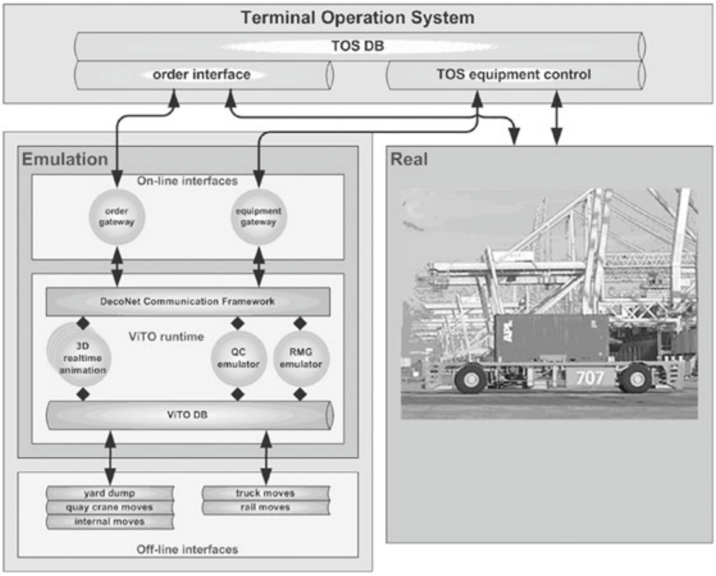

Fig. 6.5 AGV acceptance test using emulation

device, the information is sent via the order or equipment gateway to the DeCoNet communication framework. All emulators (*e.g.* for STS and RMG crane) and all other connected modules (3D animation module, report module and others) may receive this information. The emulator addressed will act like the real device and will send status information as required. The 3D animation module will refresh the output the recording module will write status information into the ViTO database. The off-line interfaces enable the layout initialization and generate the orders caused by external equipment.

The methodology described has been used for the planning, start up and is still in operation at the fully automated Container Terminal Altenwerder in Hamburg (Germany). Each software release is still tested against the emulators before ‘going live’ at the terminal. Also Saanen (2004) and Ha (2007) describe similar approaches. Currently Eurogate IT Services GmbH has made a contract with ISL to employ the ViTO environment for optimizing and emulating the terminals of the Eurogate group (see Figure 6.6).

6.4 Evaluating Ecological Impacts

More and more ecological impacts become important for container terminal planners. Therefore, the integration of these aspects into simulation tools is state of the art. As an example the inclusion of an acoustical analysis into the simulator SCUSY will be shown in this section. The aim is to provide the planner of a container termi-

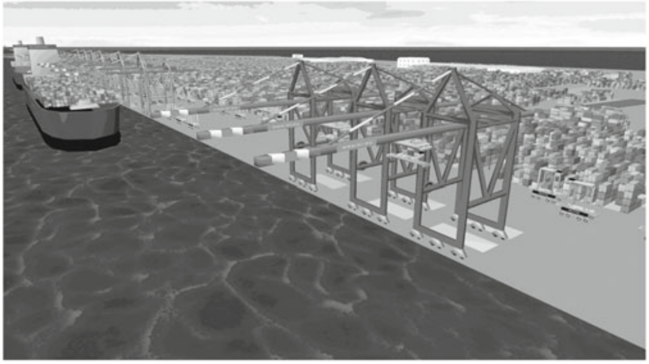

Fig. 6.6 Screenshot of the emulation of Eurogate's Container Terminal Bremerhaven (Germany)

nal with noise-relating evaluations. It shall be mentioned that the planner still works within the same environment using his well known tools and that any noise-relating facts are reduced to a minimum.

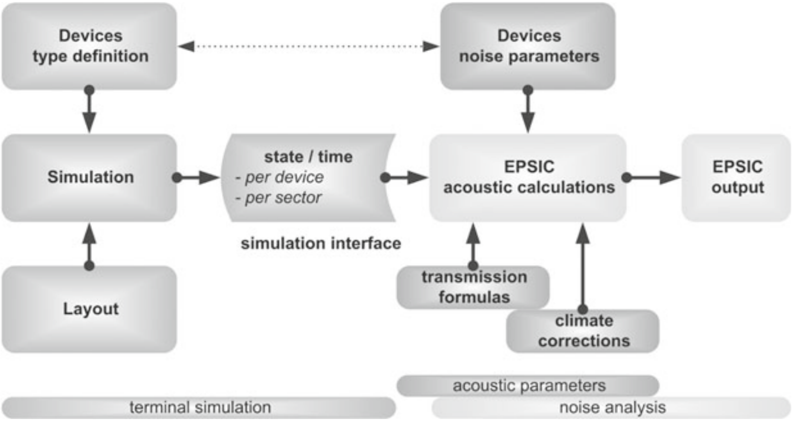

Fig. 6.7 Modules of the noise evaluation enhancement called EPSIC (see Hünerberg et al (2009)).

The implementation needs the following three steps (see Figure 6.7):

- **Generating sound emission in SCUSY**
  Inside the simulation system all devices used are included with their technical parameters (device type definition), as far as they are required for the task of productivity- and cost-evaluation. Additionally, a database was created containing known types of devices and their noise values for different states of operation (device noise parameters). Afterwards these values will be used to calculate the emissions of the terminal by allocating type related parameters to the devices being part of the simulation experiment. Noise emissions are created in

each active operating state, *i.e.* when a device moves around, receives/delivers a container or even when it is standing still with running engine. The first step to get emission values is to find out where the device operates. Although the simulation knows on which location the device is working on, collecting values relating to the whole terminal would be too undifferentiated. Each action generated by the simulation will be recorded in a given time pattern (1 hour) and assigned to the corresponding sector(s). After the simulation finished there will be information for each sector which device has worked how long in which operating state (state / time).

- **Noise transmission in SCUSY**
  While generating device related emission values is part of the SCUSY main module, the noise propagation calculation is realized by means of an additional module. The (transmission) formulas using climate correction parameters correspond to the norm DIN ISO 9613-211 (see DIN (1999)). The calculated emission results can be provided as one overall value and as value for each sector of the (terminal) area under investigation. Figure 6.8 illustrates the graphical output which allows a fast overview in this regard. Each sector of the emission diagram is dyed regarding the amount of noise emissions calculated in respect of particular measuring points.

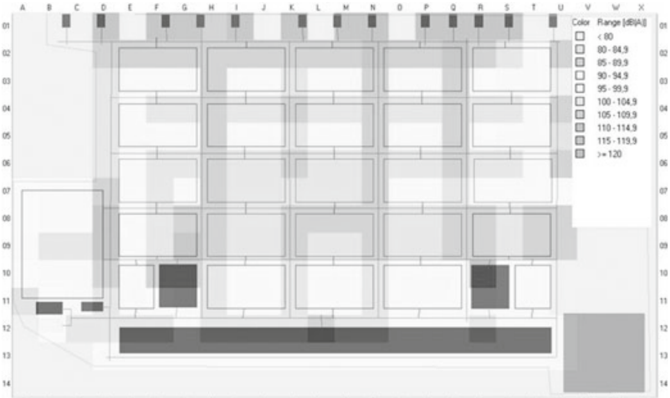

Fig. 6.8 Noise emission of each sector of the terminal (color regarding the amount of noise emissions)

- **Defining measuring points**
  In reality these points generally comply with the position of the housing constructions. Within the framework of simulation they may be defined flexible inside the additional module. Because the terminal is divided into smaller sectors, the sound influence of each sector to the measuring points is predictable. This could be used, for example, to show that the cargo handling in the train

area (located at the bottom of Figure 6.8) has the biggest influence on the noise power at these locations.

A planner using related emission diagrams can identify sound sources that have a great impact on the target locations and he is able to modify the planning at short notice. Relocating areas with a strong noise impact or implementing noise protection packages may help to reduce the noise impact at the target location. This tool gives the planner the possibility to make noise-relating decisions at a point in time long before the beginning of the licensing procedure for envisaged construction measures, which may avoid protracted, and therefore, expensive amendments.

6.5 Conclusion

Nowadays, there is a large range of simulation tools which are mostly used in the planning phase of new (greenfield) terminals or for reorganization of existing ones. More and more simulation technology is also applied within the implementation phase and will be employed in the operational phase, too. In this case (called emulation) interfaces between the model built with the emulation environment and the TOS are necessary to combine the material flow of the emulation models with the information flow (*i.e.* strategies used for resource control) of the TOS.

Furthermore, ecological impacts may be analyzed. The latest module of the tool described above combines the simulation of the terminal operation with sound emission parameters. Using transmission formulas the noise impact of a terminal at any point in the surrounding area may be calculated. As a result the terminal planner is able to evaluate related impacts in a very early planning phase, long before the licensing procedure forces him to do. At this stage a re-planning is much cheaper than it will be later on. In a similar way the carbon footprint of the terminal may be calculated by assigning emission parameters to the device types in use.

By making simulation technology accessible to logisticians and management, numerous software solutions have helped simulation to find its way into the logistics and provide support *e.g.* for planning ‘greenfield’ projects, optimizing processes, and implementing new control strategies, thus, contributing to major cost savings and quality improvements in the industry.

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Chapter 7
Step by Step Towards the Goal
The Competence Management System: An Innovative Educational Concept for Maritime Logistics

ma-co maritimes competenzcentrum
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Abstract
For a smooth process flow of the logistics chain at the system's interfaces, the operators of container terminal facilities require precisely chosen, qualified personnel. The modular approach to advanced education and training in maritime logistics is a modern educational concept that fulfills the requirements of the European Qualifications Framework for standardized vocational and educational training. It is an essential part in the development of the Hamburg Competence Management System. It comprises a database with more than 5,000 freely combinable training goals. The Competence Management System provides the entire training contents of the operational processes of the transport, transhipment and warehousing areas, as well as the relevant competences and job profiles. The system is able to offer a unique, individual advanced education and training concept for all activities and professions in the field of maritime logistics. Besides other service providers of the transport chain, the Competence Management System has already been put into practice by German container terminal operators. This paper takes a look at their experiences, as well as the functionality of the Competence Management System, by means of practical examples regarding the positions *Port Logistics Specialist* and *Ship Planner*.

7.1 A European Educational Concept for the Logistics Industry

Due to the increasing international trade, existing container terminals were ex-

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panded over the past few years and new ones, like those in Hamburg-Altenwerder[1] or Wilhelmshaven[2] (both in Germany), were built or are being built. The container terminal operators must ask themselves the strategic question how and when to recruit and qualify their personnel and how to develop their skills further. The job descriptions of the employees working in the logistics services are constantly changing. The demand for highly qualified specialists in the various areas is growing along with the requests for quality, quantity and flexibility of the required professional knowledge. Employees with professional certificates or degrees are required to extend their qualifications constantly to meet the changing customer demands and to keep up-to-date with technical developments. Quality, quantity and flexibility must be essential in an educational system for professional competence and also meet the requirements of comprehensive qualification. With this background in mind, ma-co maritimes competenzcentrum[3] developed a new educational concept for maritime logistics between 2001 and 2006 that fulfills the aforementioned requirements: It is practical, flexible and meets the demands of companies in a timely manner and, in accordance with the *E*uropean *Q*ualifications *F*ramework (EQF), it can be implemented all over Europe and thus facilitates mobility in the employment market. Besides container terminal operators, logistics service providers have already used the Competence Management System to train their employees in many ways (see 7.2.5).

7.1.1 International Educational Standards and Modularization

Two trends have had a major influence on the development of the Competence Management System and should be briefly reviewed here: The introduction of internationally comparable educational standards and the modularization of educational contents.

7.1.2 The European Qualifications Framework

On 14 December 2004, the ministers of education from 32 European countries decided to create a EQF to support mobility of employees and learners within the different countries by making education comparable and enabling employees to

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[1] The Altenwerder container terminal of Hamburger Hafen und Logistik AG started operation in 2002. For more information about the Altenwerder container terminal see CTA (2010).

[2] The EUROGATE JadeWeserPort container terminal in Wilhelmshaven is scheduled to open in 2011. For more information about the progress of the facility see JWP (2010).

[3] ma-co maritimes competenzcentrum e.V. is a transregional educational provider for the port industry, based in Hamburg and Bremen (Germany), and is financed by organizing seminars and practice-oriented training courses in the seaport, logistics, maritime shipping, dangerous goods, safety and security areas.

make use of their qualifications and have them validated in other countries[4]. All countries are supposed to develop their own national qualification frameworks as a local guideline for organizing and evaluating competences by 2010[5]. The core component of the EQF are 8 reference levels (see Table 7.1) that describe the degree of knowledge[6], skills[7] and competences[8] the employees have, regardless of where these qualifications were obtained. These eight levels comprise basic general knowledge and skills (Level 1) up to mastering a highly specialized domain (Level 8). The EQF applies to all types of qualifications, from scholastic to academic education and vocational training.

The guiding principle of level assignment for the qualifications is the orientation based on Learning Outcomes. Learning Outcomes are described as the total amount of knowledge, skills and competences acquired by a person at the end of the learning process. Thus, the main question is which competences someone actually has, and not the way a person acquired these competences and what educational degrees were obtained. The assignment of qualifications and degrees to the various EQF levels shall remain the responsibility of the education politics of each individual country[9].

7.1.3 Modularization of Vocational Education and Training

Since the beginning of the 1990s, the modularization of vocational education and training has been the topic of worldwide discussions. The literature defines the term “job qualification” as a combination of partial competences or modules that are required for job-related decision-making and responsibility (see Kloas (1997)). The German Commission for the Reduction of Unemployment and Restructuring of the

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[4] The EQF was accepted by the European Parliament and the European Council on 23 April 2008 (see EC (2010)).

[5] The Federal Ministry for Education and Research and the Conference of the Ministers of Education and Cultural Affairs introduced a draft of the German Qualifications Framework in March 2009. For current information on the development (see DQR (2010)).

[6] Knowledge means the outcome of the assimilation of information through learning. Knowledge is the body of facts, principles, theories and practices that is related to a field of work or study. In the context of the European Qualifications Framework, knowledge is described as theoretical and/or factual (see EC (2010)).

[7] Skills mean the ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of the European Qualifications Framework, skills are described as cognitive, involving the use of logical, intuitive and creative thinking, or practical, involving manual dexterity and the use of methods, materials, tools and instruments (see EC (2010)).

[8] Competence means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development. In the context of the European Qualifications Framework, competence is described in terms of responsibility and autonomy (see EC (2010)).

[9] The EQF-Ref project seeks to facilitate communication to enhance learning from each other and to develop ‘mutual trust’ in referencing qualification levels to the EQF. In particular, the project seeks to identify procedures of ‘good practice’ for referencing qualifications levels to the EQF and to propose the structure of the EQF referencing reports (see EQF (2010)).

Table 7.1 The eight reference levels of the European Qualifications Framework (see EC (2010))

	Leaning Outcomes		
Reference Level	Knowledge	Skills	Competence
*Level*1	basic general knowledge	basic skills required to carry out simple tasks	work or study under direct supervision in a structured context
*Level*2	basic factual knowledge of a field of work or study	basic cognitive and practical skills required to use relevant information in order to carry out tasks and to solve routine problems using simple rules and tools	work or study under supervision with some autonomy
*Level*3	knowledge of facts, principles, processes and general concepts in a field of work or study	a range of cognitive and practical skills required to accomplish tasks and solve problems by selecting and applying basic methods, tools, materials and information	– take responsibility for completion of tasks in work or study – adapt own behavior to circumstances in solving problems
*Level*4	factual and theoretical knowledge in broad contexts within a field of work or study	a range of cognitive and practical skills required to generate solutions to specific problems in a field of work or study	– exercise self-management within the guidelines of work or study contexts that are usually predictable, but are subject to change – supervise the routine work of others, taking some responsibility for the evaluation and improvement of work or study activities
*Level*5	comprehensive, specialized, factual and theoretical knowledge within a field of work or study and an awareness of the boundaries of that knowledge	a comprehensive range of cognitive and practical skills required to develop creative solutions to abstract problems	– exercise management and supervision in contexts of work or study activities where there is unpredictable change – review and develop performance of self and others
*Level*6	advanced knowledge of a field of work or study, involving a critical understanding of theories and principles	advanced skills, demonstrating mastery and innovation, required to solve complex and unpredictable problems in a specialized field of work or study	– manage complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts – take responsibility for managing professional development of individuals and groups
*Level*7	– highly specialized knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking – critical awareness of knowledge issues in a field and at the interface between different fields	specialized problem-solving skills required in research and/or innovation in order to develop new knowledge and procedures and to integrate knowledge from different fields	– manage and transform work or study contexts that are complex, unpredictable and require new strategic approaches – take responsibility for contributing to professional knowledge and practice and/or for reviewing the strategic performance of teams
*Level*8	knowledge at the most advanced frontier of a field of work or study and at the interface between fields	the most advanced and specialized skills and techniques, including synthesis and evaluation, required to solve critical problems in research and/or innovation and to extend	demonstrate substantial authority, innovation, autonomy, scholarly and professional integrity and sustained commitment to the development of new ideas or processes at the forefront of work or study contexts including research

Federal Labor Office criticized a few years ago that vocational education and training as the central tool of active labor market politics in Germany takes place in a rather haphazard, selective and uncoordinated way. It was further mentioned that the German education market with its 28,500 educational providers was very heterogeneous, making comparisons and overviews more difficult. The Commission thus demanded, that the educational offerings be modularized. A modular structure ensures flexible adaptation to the demands of companies and individuals (see Hartz (2002), p. 159).

Modular concepts have gained prominence in the education sector over the past few years[10]. Modularization is generally credited with enabling better coordination and thus better coherence in the rather non-standardized educational system. Individuals without formal professional degrees and the much sought-after flexible employee with a lifelong continuing learning pattern are supported, while flexible learning paths and possibilities for acceptance of previously received degrees and informally obtained qualifications are being created (see Kloas (1997)).

7.2 Qualification Based on Modularization: The Competence Management System

Already in 1997, the Australian National Training Authority has led the way to modular educational concepts by developing a modular training concept for transport and distribution: the Transport & Distribution Training Package[11]. Following this example, and in an attempt to close a gap in Europe, the Competence Management System was developed in Hamburg in 2006. We will have a look at the history and the functionality of the Competence Management System in the next few sections and take the training paths for the *Port Logistics Specialist* and the *Certified Ship Planner* as examples.

7.2.1 The History of the Competence Management System

In order to comply with the demands of the logistics companies and the European educational requirements, ma-co maritimes competenzcentrum (called Fortbildungszentrum Hafen Hamburg at the time), the Logistics Research Group[12] and

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[10] An overview of the modularization in vocational training and the current state after 20 years of discussion and various implementation attempts in Germany, Austria, Switzerland and the United Kingdom can be found in Pilz (2009)

[11] Participants of this training program choose modules (units) that lead – combined with others – to a qualification complying with all required competences of a job profile or a professional qualification (see Anonymous (1997), page 3).

[12] The Logistics Research Group e.V. was founded in Hamburg in 1992 by companies collaborating with the “Arbeitsgebiet Technische Logistik” (Technical Logistics Work Group) of the Technical

the Coordinating Office for Education, Training and Employment[13] (upon special request by the EU) developed the modular concept for logistics training in 2006. Within the framework of the European Social Fund's qualification initiative "Gelernt ist gelernt" ("Education Pays", see Anonymous (2007)), the first step was a comprehensive IT solution that collected and organized more than 5,000 detailed logistics-related learning goals for 500 competences in a logistics competence database, the Competence Management System. All tasks and their associated activities and functions[14] in the transport, transhipment and warehousing business are represented in the Competence Management System. The Competence Management System helps to train all employees in the industrial/technical or commercial areas of this industry. Holland is the only country in Europe with a comparable, internationally viable modular training concept for the logistics industry. In addition to creating the Competence Management System, the other purpose of the "Gelernt ist Gelernt" (Education Pays) project, sponsored by the European Social Fund, was to develop qualification profiles for the transport and logistics areas that cater to the long-term needs of job seekers, employees and companies, and to offer a flexible system that can meet the ever-changing demands of the industry. Besides specialized and IT qualifications, employees are also required to have advanced soft skills, such as taking on responsibility, the ability to act independently, abstract thinking, willingness to collaborate, flexibility, self-learning skills and the willingness to learn. Against this background and with special focus on learning methods and organization, the project concentrated on the transfer of conventional (specific) knowledge to modular, quickly adaptable learning units that support learning at the workplace, as well as self-organized, self-directed learning and training with new media.

7.2.2 The Functionality of the Competence Management System

The Competence Management System is based on process-oriented competence profiles that represent the logistics chain and thus its relevant work processes: for example, the competence profiles goods receiving, incoming goods, internal transport,

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University Hamburg-Harburg to support the logistics research and to make new findings available for practical application.

[13] The Coordinating Office for Education, Training & Employment e.V. in Hamburg implements qualification and employment strategies for companies of the public sector in the EU, Germany and the larger Hamburg area. Their services comprise full-scale management of projects for different target groups in a variety of industrial sectors.

[14] Operational functions are considered as assignments of defined areas of responsibility to single company instances or the company itself.

storage, order picking, packaging and shipping. These competence profiles can be further divided into practical competences[15] and learning goals[16] (see Figure 7.1).

The competences and competence profiles can be combined flexibly and freely, depending on the demands of the company or the trainee. The Competence Management System is dynamic, which means it is constantly adapted to changing demands and developments and updated regularly. It also offers the possibility of acquiring partial certificates and vocational degrees for the German market. A defined amount of competence profiles qualifies the trainee to participate in final exams of the Chambers of Industry and Commerce responsible for the certification of vocational qualification exams in Germany (*e.g.* the job qualifications *Port Logistics Specialist*, *Warehouse Specialist*, *Warehouse Logistics Specialist*, *Skilled Port Worker*, *Warehousing and Logistics Manager*). European certificates offered by the *E*uropean *L*ogistics *A*ssociation (ELA) for the Supervisory / Operational Level and Advanced Level Logistics are also available. Thus, the Competence Management System provides the basis for the vision of qualifications and certifications that are valid all over Europe.

7.2.3 Using the Competence Management System to Define the Job Qualification for **Port Logistics Specialist**

In order to create a job profile[17] such as the two-year training for *Port Logistics Specialist*, the competence managers of ma-co maritimes competenzcentrum, in coordination with the companies, combine the relevant training contents via the Competence Management System user interface. For the job profile *Port Logistics Specialist*, approximately 230 learning goals[18] are determined, which are then grouped into 68 competences[19]. These result in eleven competence profiles[20]. The combina-

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[15] The Competence Management System defines competences as skills required for the independent execution of self-contained work processes that, in turn, consist of specific operational activities.

[16] In terms of acquiring competences or associated skills respectively, it is possible to define different learning goals for each employee. Learning goals are the smallest units in the Competence Management System; they describe the intended learning achievement in related to a specific content. For example, one of the learning goals in the competence profile “Receiving Goods” is “Control the delivered goods”.

[17] The term “job profile” corresponds to the definition of a job qualification according to Kloas (1997).

[18] The learning goals “Comparing documents and claiming differences” and “Control the delivered goods” result in the competence “Check goods receiving documents” (see Figure 7.2).

[19] The competence profile “Receiving Goods” (see Figure 7.2)contains the six competences “Check goods receiving documents”, “Check goods in receiving area”, “Receiving goods”, “Prepare goods for storage”, “Environmental protection in the goods receiving department”, “Organize the goods receiving process”.

[20] The eleven competence profiles for *Port Logistics Specialist* are “Present port logistics processes”, “Receiving goods”, “Check goods (type-specific)”, “Check goods (cargo-specific)”,

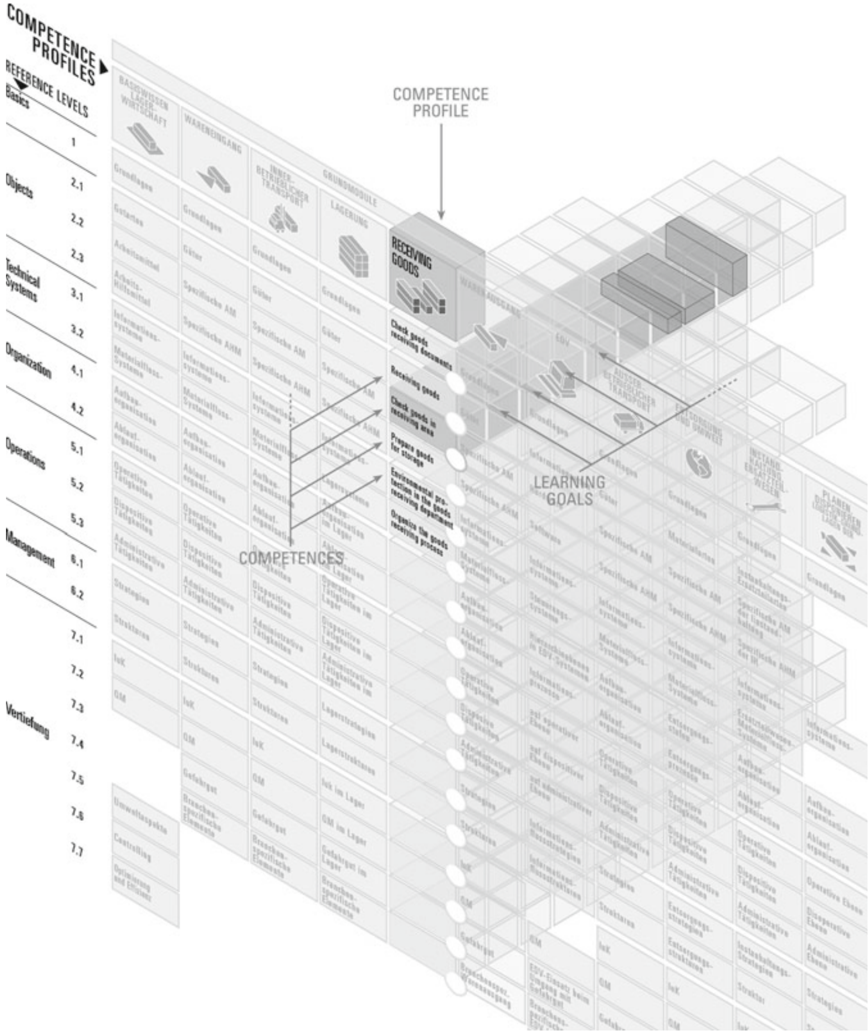

Fig. 7.1 The Competence Management System with its competence profiles, competences and learning goals

tion of several competence profiles then forms the basis for qualifications such as vocational degrees and trainings (see Figure 7.2).

"Check containers", "Store and process goods", "Transport goods on-site", "Plan and execute loading and unloading processes", "Process transhipment and shipping documents", "Load and secure containers", "Control and secure dangerous goods" (see Figure 7.2).

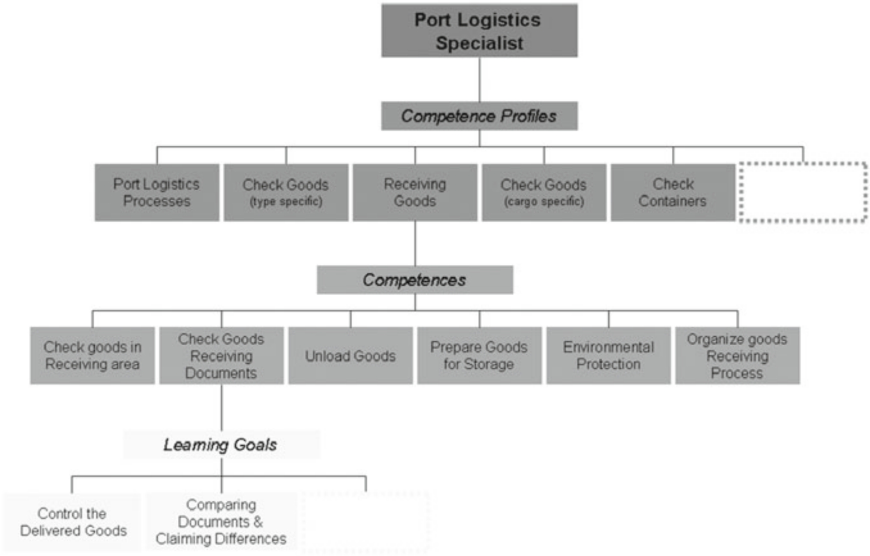

Fig. 7.2 The job profile *Port Logistics Specialist*

7.2.4 Using the Competence Management System to Create the Training for Certified Ship Planner

Another example of the functionality of the Competence Management System is the training for *Certified Ship Planner*. Ship planners are responsible for the IT-supported planning and supervision of loading and discharging of container vessels and work in the stowage department of shipping companies or container terminal operators. Until that time, there had not been a regulated training course for this position. Previously it required a nautical patent, but a shortage of nautical specialists forced the companies to offer on-the-job training for career changers.

For professionals with at least two years of experience in the “port/ship interface” area or a completed vocational degree as sea shipment controller, freight-forwarding manager or ship broker, ma-co maritimes competenzcentrum, the University of Bremen and the Coordinating Office for Education, Training and Employment have developed an extra-occupational modular training based on the Competence Management System. In order to meet the requirements of modern maritime shipping at sea and on land the academic qualification was extended to be part of the vocational training, while making it available for new target groups. The extra-occupational additional qualification, *Certified Ship Planner*, is classified as EQF level 4. The course is taught in English. By issuing credit points, the extra-occupational additional qualification, *Certified Ship Planner*, is internationally comparable and applicable. The advanced training *Certified Ship Planner* consists of nine competence profiles (see Figure 7.3): “Occupational Field and Environment”, “Container Ships/Multipurpose Ships", "Maritime English", "Hazardous Goods/Special Goods", "Internship in a (feeder) shipping company", "Stowage Planning", "Online Stowage Planning", "Internship at a terminal operator", "Final Paper/Exam". The theory block phases last one week (60 lessons) each, the practical phases last 120 lessons each. There is a final exam at the end of each training. The second Competence Profile "Container Ships/Multipurpose Ships", for example, consists of five competences: "Ship Types", "Constructional Demands of Stowage Planning and Containerization", "Stability Demands and Presentation of the Physical Basics and Calculation of Forces", "Mechanical Stresses in Maritime Traffic" and "Actual Behavior of the Ship with Cargo on Board". For the competence "Ship Types", the following learning goals have been defined in terms of associated activities and applicable skills: "Feeder ships", "large container ships", "multi-purpose ships", "special considerations for stowage planning and stability calculation".

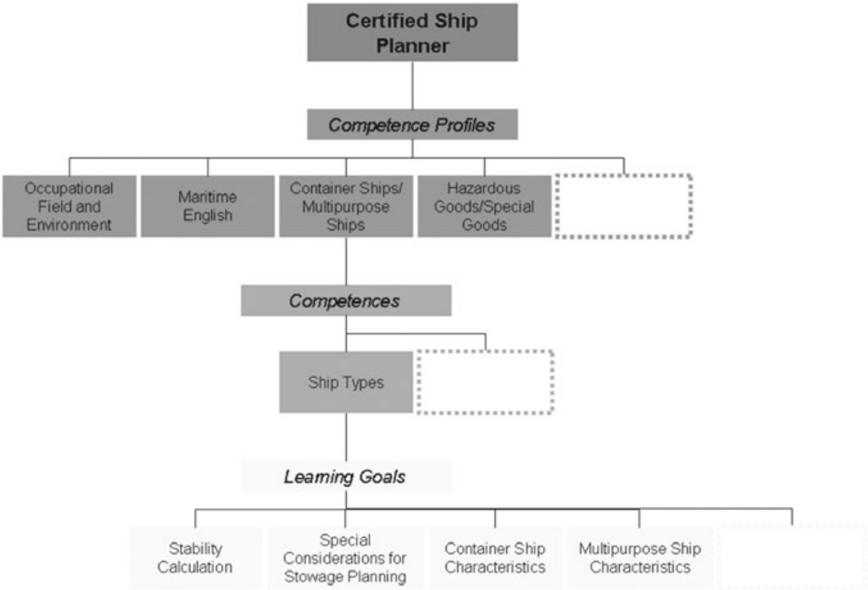

Fig. 7.3 The vocational training *Certified Ship Planner*

7.2.5 *Qualification Options of the Competence Management System – Example: German Container Terminal Operators*

The Competence Management System offers companies of the transport, transhipment and warehousing sector a flexible tool for the setup of qualifications in accordance with the market needs. As regards tool application, the company must first consider two basic issues: Does the company require a comprehensive qualification with an officially recognized vocational degree (qualification strategy [A]) *or* will a shorter, modular training and qualification strategy suffice that provides the necessary competences for the respective activities stipulated by company (qualification strategy [B])? Both training paths are valid options and – under the prevailing conditions at the time – the Competence Management System can effectively support their target-oriented conception and implementation. Important: Both options result in a comprehensive vocational training of the personnel.

Besides several transport chain service providers, two large German container terminal operators have already tested the Competence Management System in practice, *viz.:* for the start-up operation of new facilities and for the development of human resources at a container terminal already in operation. Both companies completed the courses successfully according to their respective needs.

The human resources development managers of the Container Terminal Hamburg-Altenwerder initially decided to provide their employees with single competences to ensure the terminal's operational capacity right from the start (qualification strategy [B]). Individually appointed human resources development teams first determined the minimum qualifications required for the terminal to start operation. For example, it was examined in which area of the terminal container transfers should take place, which check-up tasks must be performed according to which processes and requirements and thus the required competences of the staff performing these jobs.

In order to assign the identified competences to separate job positions and thus define operational functions, a job position determination was added. Function by function – from container checker to customs manager and quay crane operator – was determined, a corresponding competence profile was created and human resources planning was drawn up. In the end this showed the number of single competences needed and to which extent employees should acquire two or more competence profiles due to the structure and amounts of work arising in the different terminal areas.

The employees were not hired until shortly before the start of terminal operation and were fitted with two to three competence profiles by qualification measures that lasted three months on average. For example, container checkers were qualified in such a way that they were able to cover all relevant check position of inbound and outbound container transports within the terminal area. Supervisor functions were additionally assigned to quay crane drivers and drivers of terminal tractors also received the competence profile "Check Gate". Later, during the course of their employment, they were provided with continual training to obtain additional competence profiles. Currently, the terminal employees master a variety of competences and can be used flexibly for different functions in the terminal operation.

Advantage of Qualification Strategy [B]: The costs prior to the start of operation are comparatively low, since the majority of new employees was hired three to six months before this date and terminal staff was initially educated in specific operational skills (and not comprehensively). At that point in time, all cranes an terminal vehicles were already available and parts of the training could already be performed in trial operation.

A second operator, the EUROGATE company, has chosen the alternate path for its new container terminal in Wilhelmshaven: Their objective was to have comprehensively qualified employees available at the start of terminal operation in 2011 (qualification strategy [A]). In addition, the measures were supposed to provide an impetus for employment in a region with a high amount of job seekers. It was also intended to provide people without any port-related knowledge with a comprehensive introduction to port operation in general and, based on this knowledge, to focus qualification on the central competences of container terminal operation.

The operator thus started early, three years before of the opening date, with the recruitment and qualification of employees. Applicants were selected in assessment centers and then trained for two years as *Port Logistics Specialists*. This specialized occupation in port operation comprises a variety of competence profiles: From the basics of port operation to comprehensive occupational safety topics, customs regulations and their implementation, dangerous goods transport regulations and their operational implementation and devices and facilities enabling horizontal and vertical cargo transports within the port or terminal area, respectively.

Advantage of Qualification Strategy [A]: Although the upfront cost was high, the operator was be able to use flexible and comprehensively trained employees at the start of container terminal operation, who can quickly adapt to new tasks. Terminal staff has obtained a complete overview of the terminal processes during their training, which allows for fast optimization of operations processes or single functions and interfaces. In addition, it was possible to build up a high loyalty to the company during the relatively long qualification phase, which will help prevent fluctuation in the future.

As a result of the training and human resources development strategy and the aforementioned qualification paths, there are comprehensively trained, terminal-independent specialists. Both container terminal operators provided qualification measures for about 300 employees. There is currently not enough data available for a final evaluation, due to ongoing human resources development efforts. From a general point of view both occupational training approaches are quite suitable for purposeful human resources development of companies.

In the first instance, decision making for the "right" qualification strategy is influenced by the companies' training objectives an economical evaluations, as well as by the timeframe available for realization. Also the location of the company and the infrastructure of the region and its educational policy frequently have an impact in choosing this specific strategy.

7.3 Beneficial Impact of the Competence Management System

The various groups involved in a company project usually have their own specific view of the project progress and (activity) requirements arising within their area of responsibility. In the field of vocational and advanced training, the Competence Management System can provide valuable support for a common understanding of project objectives and necessary actions by describing relevant measures and processes clearly and comprehensibly using precise definitions and thus (ideally) creating consensus among all participants involved in the project. Terminal management or human resources developers, chief instructors or trainers, specialty departments or occupational safety authorities – everybody talks about the same contents and competence requirements. The Competence Management System can thus (as a communication tool) take on a central role within the framework of human resources development processes. While the usual "job descriptions" remain rather generalized, the Competence Management System enables detailed descriptions of single competences and competence profiles required for specific job qualifications based on existing learning goals. This greatly increases the quality of the information for respective projects and improves the information exchange between the participants. As part of the continuing human resources development, other competence profiles can be easily and quickly added through advanced training initiatives to support employee motivation, company loyalty and each individual's career. All in all, the Competence Management System is able to provide far more efficiency and effectiveness during conception and implementation of companies' vocational and advanced training processes, which results in positive outcomes or successful educational efforts, respectively. Therefore, the Competence Management System is an effective instrument for companies in the field of personnel qualification; so far, it has mainly been used in the logistics services area.

In summary, the system offers the following advantages:

- Creating a common communication basis for all groups involved in the qualification measures
- Tailor-made fulfillment of individual company needs
- International versatility of trained employees by adherence to European educational guidelines
- Topicality by constant adjustment of contents to changing labor market needs
- Timely generation of applicable results by comparatively quick setup of competence profiles
- High effectiveness in terms of quality and quantity of the achieved vocational and advanced training results
- Cost savings by eliminating to a great extent the demand for expensive consulting services
- Control and monitoring of qualification status within the scope of vocational and/or advanced training projects, as well as use for planning purposes (*e.g.* as training schedule)
- Cost and time savings by the comparability of competence profiles, *i.e.* overlaps and duplicity of qualification activities can be purposefully avoided.

In view of the application options described above, the Competence Management System can support terminal planning projects mainly by designing or developing activities in the field of human resources. Based on the handling and transport technologies, as well as the organizational structures envisaged for new constructions or expansions of container terminals, the required staff must be qualified accordingly and the competence management system offers the necessary support.

Within the construction phase, any initiated vocational and advanced training measures can be supervised by the Competence Management System to ensure a timely qualification progress. After the start of the terminal operation, the system should be incorporated into continuous human resources development processes to provide long-term support for the conception and implementation of companies' qualification initiatives. Figure 7.4 shows an overview of the various application options for the Competence Management System:

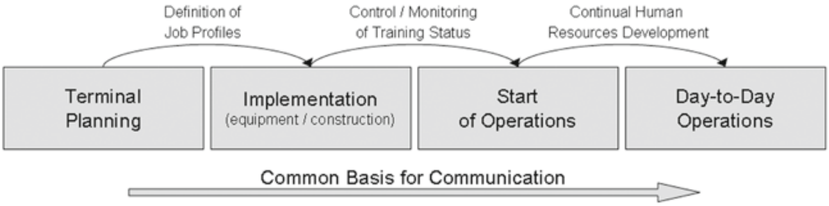

Fig. 7.4 Application areas of the Competence Management System during planning and realization of container terminals

7.4 Conclusion

The modular Competence Management System with its structure of competence profiles, competences and learning goals contains all tasks and activities in the transport, transhipment and warehousing areas. It is an effective tool that helps to educate all employees (on all operational levels) in this industrial sector. The use of the Competence Management System within vocational and advanced training measures significantly increases the effectiveness and efficiency of companies' qualification processes. This is mainly due to the improved communication and information between all participants, as well as the flexible use of the system for each individual case.

Experiences at seaport container terminals have shown that the Competence Management System greatly facilitates output-oriented human resources development and can achieve significant advantages compared to existing qualification concepts, both qualitatively (as to target-setting) and quantitatively (in terms of variety and amount of training contents and training cases per time unit). Employees can be precisely trained – within the given time constraints – according to the individual terminal's requirements. Any changes in the terminal structure can be accommodated with comparatively little effort in each phase of the terminal's existence (planning – construction – day-to-day-operation) by short-term updates of the Competence Management System contents. Thus, results are quickly available for all participants and it is possible to react flexibly to any changes in the internal conditions.

It should be stressed again that the systematic use of the Competence Management System provides sustainable support and long-lasting efficiency of the strategic human resources development. This applies to new constructions and expansions of container terminals, as well as to their day-to-day operation.

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Part III
Planning Area
Terminal Quayside

Chapter 8
Simulation of Container Ship Arrivals and Quay Occupation

Sönke Hartmann, Jennifer Pohlmann, and Axel Schönknecht

Abstract
This contribution presents a simulation model that generates arrivals of ships over time at a container terminal. The model includes a quay with a given length, a decision module for assigning berths to ships, and a queue for ships for which currently no berth is available. Such models are applied in practice to examine the capacity of the quay and of the quay cranes in scenarios for expected future workloads and ship arrival patterns. We outline the concept for a simple and general simulation model and present some experimental results based on real data. Subsequently, we discuss various extensions of the model that would be necessary to adapt it to a specific terminal.

8.1 Introduction

Quay walls are among the most expensive infrastructure investments in container ports. Especially in regions with significant tidal range, quay walls can achieve enormous dimensions and require substantial construction efforts. A typical modern container ship quay wall in a North Sea port has a height of about 40m from

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bottom to top (see Grabe (2008)). The costs per running meter can be as high as 65,000 EUR (see HPA (2008)). Requirements like heavier quay cranes and permanent water depths of 16m and more for the container ships of the next generation pose further requirements on quay walls.

Consequently, building quay walls requires enormous investments, and is also time intensive, based on the need for planning and construction. Hence, the decision regarding how long a terminal's quay wall should be is of tremendous importance. This holds true for both building new terminals and existing terminals, which plan an extension of their quay wall.

When facing this decision, the main difficulty lies in the estimation of what quay wall length would be appropriate to use for a certain throughput of ships and containers. A static calculation can hardly take into account dynamic effects, such as distributions of ship arrivals over time in a realistic way. Therefore, simulation suggests itself as a tool since it allows to capture the dynamic nature of the ship arrivals.

In this contribution, we outline a simple and general simulation model that generates ships of different classes (*i.e.* sizes) and their arrivals over time. The model further includes the quay wall along with strategies for assigning berths to arriving container ships. Several months of ship arrivals can be simulated, and resulting figures, such as the average waiting times of ships for a free berth are analyzed. Hence, the model is a tool for determining the terminal's service level that can be expected for a given arrival scenario and a given quay wall length.

The remainder is organized as follows. Section 8.2 provides a brief discussion of terminal capacity and quay wall length. Then Section 8.3 introduces the simulation model. Section 8.4 summarizes the results of some experiments that have been conducted using real-world data. Subsequently, Section 8.5 points out to possible extensions of the model, and some conclusions are drawn in Section 8.6.

8.2 Container Terminal Capacity and Quay Wall Length

Terminal capacity is an often utilized term in container terminal planning. Unfortunately, a precise definition of this term does not exist. While the maximum number of containers to be stacked on the terminal is often referred to as stacking capacity, the term terminal capacity usually refers to the maximal quayside throughput per year, *i.e.* the maximum number of containers (or TEU[1]) that can be discharged from and loaded onto ships per year.

However, a meaningful way to estimate the capacity of a terminal does not seem to exist. For example, the terminal capacity of the Port of Hamburg, according to its webpage, is around 8.8 million TEU per year. However, the actual throughput in 2008 was around 9.7 million TEU.

The main problem when estimating the throughput capacity of a terminal is that many factors must be taken into account. This obviously includes the length of the

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[1] TEU = twenty foot equivalent unit, i.e. twenty foot standard container

quay wall as well as the quay cranes and resources for transportation and stacking. External factors such as tidal range and schedules of container ships must be considered as well. Some impacts on the terminal capacity are displayed in Figure 8.1. The number of factors, as well as their diversity, turn the calculation of capacity into a highly complex task.

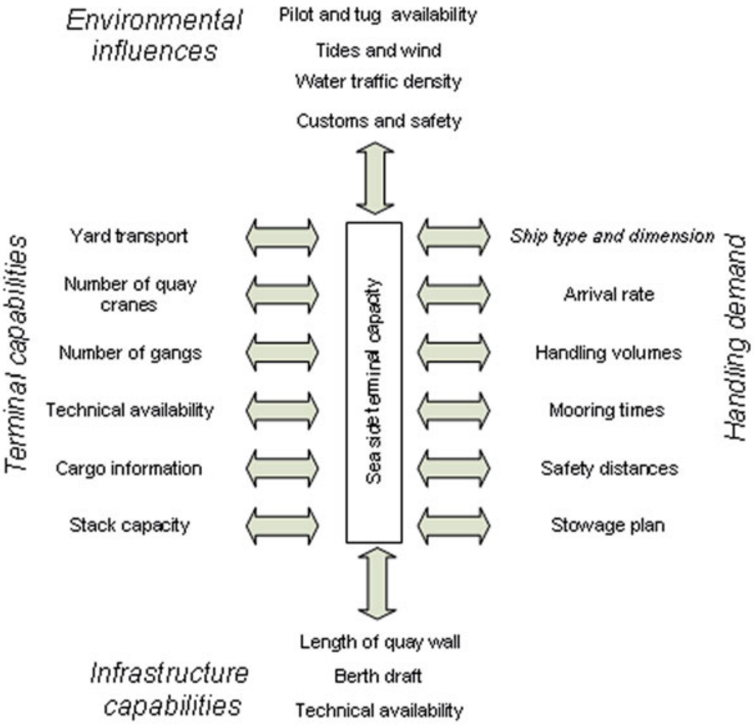

Fig. 8.1 Some impacts on the quayside terminal throughput capacity

A measure that puts the total quayside throughput in relation to the length of the quay wall is the throughput per meter. Values for different container terminals can be found in Table 8.1. The values vary strongly between the terminals. This is due to the various factors mentioned above. Especially considering the types of ships: Terminals with a large fraction of smaller feeder ships are likely to obtain less throughput per meter, since large container ships allow for much more efficient operation. When interpreting the data, however, one must be cautious, because construction efforts may have temporarily decreased the actual throughput capacity. Nevertheless, Table 8.1 indicates that the throughput strongly depends on the conditions of a particular terminal.

In the following, we discuss a simulation model that can help to determine the throughput capacity of a terminal focussing on the quay wall. Rather than a value for the throughput capacity, it provides service level indicators (such as ship waiting times) for a given quay length and workload scenario. This is because there may not be capacity restrictions in the sense of a fixed upper limit on the throughput – it is often possible to further increase the throughput, but at the cost of deteriorating service quality.

The model is based on the use of empirical distributions, which determine ship sizes, interarrival times, and berthing times. While the model itself is basically a simple queueing model, the use of empirical distributions implicitly takes into account many of the factors influencing the terminal performance that are summarized in Figure 8.1.

Table 8.1 Comparison of quay wall throughput on different terminals in 2006

Terminal	Quay Wall Length [m]	Throughput [million TEU]	Throughput per Meter [TEU/m/year]
Kwai Chung Hong Kong	2,322*	5.40*	2,325
PSA Singapore	16,000^{+}	23.98*	1,499
Shinsundae Busan	1,500*	2.08*	1,384
MSC Bremerhaven	600*	0.62*	1,040
HHLA Burchardkai Hamburg	2,850*	2.90^{o}	1,018
La Spezia	1,438*	1.00*	693

(see * Fossey (2009), $^{+}$ HHLA (2006) and ^{o} PSA (2010))

8.3 Simulation Model

This section provides a description of the simulation model. It is a rather basic prototype than a full-fledged model, and it can be adapted to any specific terminal by including further relevant requirements of that terminal. Some guidelines for extending the model will be given in Section 8.5.

8.3.1 Overall Structure

Ships of different sizes have different characteristics and are often treated differently when they are allocated to berths. This is taken into account in the simulation model by using different classes of ships. We have three classes representing small feeders, medium-sized ships and deep-sea container ships, respectively. A description of the three classes is provided in Table 8.2 (note that the parameter settings can easily be adapted by the user). As in the remainder of Section 8.3, the data is taken from a major European container terminal.

The simulation model consists of three main stages. The first one generates arriving ships and the ship-related information. We have a separate set of parameters

Table 8.2 Description of the ship classes used in the simulation model

Ship Class	Description	Capacity	Percentage of Total Number of Ships	Percentage of Total TEU Throughput
1	small feeder	up to 1,500 TEU	87.3%	27.4%
2	medium-sized	1,500 - 6,000 TEU	7.3%	27.6%
3	deep-sea ship	more than 6,000 TEU	5.4%	45.0%

for the generation of each ship class. The second component is the queue for ships. Whenever a ship arrives at the terminal, it is appended to the queue. There is one single queue for all ships. The third component is the quay of the terminal. The queue and the quay are managed by a specific logic that decides which ship is next to moor and which berth it is assigned to. The structure of the simulation model is sketched out in Figure 8.2. The components of the model are detailed in the following sections.

All of the relevant input information such as sizes of ships, times between arrivals etc. can be specified by the user in terms of empirical distributions. The reason for this approach is that it allows the user to adapt the behavior of the simulation model to any terminal by taking statistical data from this terminal. In addition, most real distributions taken from the terminal mentioned above did not match any theoretical distribution type. For example, the interarrival times are approximately exponentially distributed only for small feeders. For medium- and large-sized ships the distribution is irregular, which is due to specific schedules of container ships and other factors such as tidal range. Therefore, we consider empirical distributions to be more realistic than theoretical distribution types that are often used in simple queueing models.

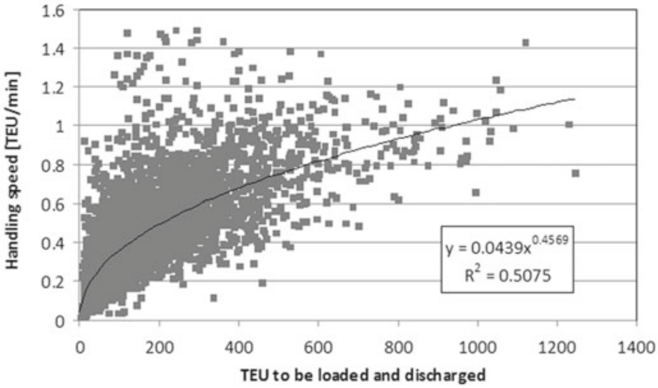

Fig. 8.2 Schematic view of the simulation model

The distributions, together with the length of the quay, are the main parameters which can be controlled by the user. Each of the three ship classes is associated with an individual set of distributions.

8.3.2 Generation of Ship Arrivals

Whenever an arrival of a new ship of a particular class is generated, the following information must be determined: the time between the arrival of the previous ship of the same class and the arrival of this ship (interarrival time), the length of the ship (*i.e.* the portion of the quay it will occupy), and the handling time of the ship (*i.e.* the time span it will occupy the quay).

As mentioned in Section 8.3.1, all data is generated randomly based on empirical distributions. In the following, we provide some details on the methodology for ship generation. The explanations are illustrated by means of (shortened) example distributions for the first ship class, *i.e.* small feeders. The distributions were taken from the aforementioned major European terminal.

The first step is the generation of the **interarrival time**. Table 8.3 gives an example for distribution of related times, which has been shortened since the actual table would be too long. Note that interarrival times are not the only possible basis for such a simulation model. For instance, Hartmann (2004) uses distributions for ship arrival patterns over a week and during a day. However, the scope of that generator is a more general one, and for rather simple queueing models, like the one considered here, interarrival times are a common approach.

Table 8.3 Distribution of interarrival times (small feeders)

Probability	Interarrival Time [minutes]
0.155	6.5
0.102	23.1
0.083	38.1
0.071	52.7
0.057	67.7
(...)	(...)

The second step is the generation of the **ship size**. Based on a distribution a ship is assigned a length and a capacity. An distribution example is displayed in Table 8.4. The third step is the generation of the **ship handling time** at the terminal, *i.e.* the time for discharging and loading. The handling time depends on the number of containers that is discharged and loaded. The number of containers is measured here as a percentage of the ship's total TEU capacity. Note that the largest possible percentage is 200% because all containers could be discharged and then the empty

Table 8.4 Distribution of ship length and capacity (small feeders)

Probability	Length [m]	Capacity [TEU]
0.001	80.8	68.7
0.011	88.8	204.7
0.021	92.4	268.7
0.094	99.3	379.0
0.145	101.3	480.7
(...)	(...)	(...)

ship could be fully loaded (values above 100% do occur in practice but are very rare). Table 8.5 gives an example distribution.

Table 8.5 Distribution of handled containers (small feeders)

Probability	Percentage of Capacity
0.043	3.4%
0.131	7.7%
0.139	12.4%
0.139	17.5%
0.119	22.6%
(...)	(...)

The only scarce resource in our model is the quay, since the quay cranes are not modeled explicitly. Therefore, we cannot determine the ship handling time using the number of handled containers and the available quay cranes over time (also see Section 8.5.3 on this issue). Consequently, a different approach is needed. We determine the ship handling speed by means of the number of TEU handled per minute per ship. This handling speed can easily be derived from terminal or port statistics. The ship handling time is then obtained from dividing the number of handled containers by the ship handling speed. For example, we may have drawn a ship with a capacity of 1,000 TEU, and 25% of its capacity is discharged and loaded, so 250 TEU are handled. If we have a speed of 0.547 TEU per minute (which could be realistic for a small feeder), we obtain a ship handling time of 457 minutes (7.6 hours).

There is a strong correlation between the number of TEU handled and the handling speed; the correlation coefficient is 0.88 when ships of all classes are considered. This is due to the fact that the smaller a ship and the smaller the number of containers handled, the more often quay cranes must change the ship bay, which is time consuming and slows down the discharging and loading process. Even within a ship class, there is still a dependency. As a consequence, we cannot simply draw the handling speed from a distribution, because we might get a slow speed for a ship with many containers and hence an unrealistically long ship handling time.

Therefore, the handling speed is modeled as a function of the number of TEU to be loaded and discharged. For each ship class, a separate function is defined. For each of the first two classes (small feeders and medium-sized ships), a function of the type $y = a \times x^b$ are estimated using nonlinear regression. For the third class (deep-sea container ships) a function of the type $y = a \times x + b$ was estimated using linear regression. As an example, the ship handling time function (as well as the observations used for the estimation) for small feeders is shown in Figure 8.3.

It should be mentioned that the empirical ship handling times which are the basis of this calculation have been determined as the difference between actual ship arrival and departure time. Hence, extended handling times due to scarce resources are included, such that the ship handling times implicitly contain the availability of the terminal resources (in particular quay cranes and horizontal transport).

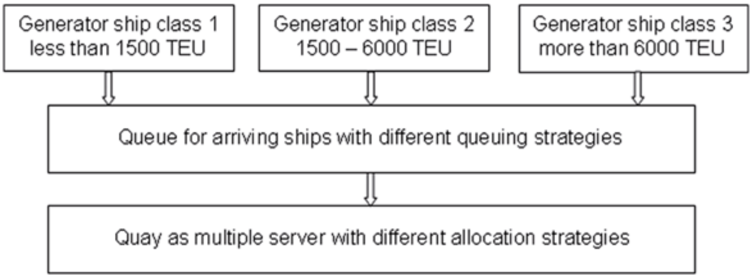

Fig. 8.3 Relationship between handled containers and handling speed (small feeders)

8.3.3 Berth Allocation

The simulation model captures one continuous quay, and the conditions such as quay crane types, water depth etc. are the same everywhere along the quay wall. That is, any ship can berth anywhere. Specific conditions that might have an influence on arrival or departure such as tide or traffic conditions are not taken into account. For modeling purposes, the quay is discretized, that is, divided into segments of constant length (50m). A single segment cannot be shared by two ships. Thus, a ship will always be assigned to the smallest possible number of quay segments that covers its length plus a required minimum distance that must always be kept between two ships (due to mooring and safety reasons). For example, a ship with a length of 160m and a safety distance of 25m requires 185m of space, which translates to four consecutive segments occupied by this ship.

Berth allocation is triggered by arrival and departure events, that is, whenever a ship arrives or a ship leaves the terminal (and at least one other ship is waiting in the queue), the berth allocation component is called. It is responsible for two decisions, namely, which ship in the queue will be next to obtain a berth at the quay and at which position this ship will berth.

The first step of the berth allocation process is to select the next ship from the queue. The simulation model currently offers two alternative selection approaches. The first one is the *F*irst-*C*ome-*F*irst-*S*erve (FCFS) rule, which means that the ship with the earliest arrival time is selected. The second one is based on the *E*arliest *D*ue *D*ate (EDD) rule. The latter defines a due date for the completion of a ship as the arrival time plus the ship handling time plus a buffer time, which reflects the urgency of the ship. We have an individual buffer time for each ship class (6 hours for small feeders, 4 hours for medium-sized ships, and 2 hours for deep-sea container ships).

An additional option is to give priority to deep-sea container ships. If this is done, a small or medium-sized ship can only be assigned to a berth if no deep-sea container ship is in the queue, and the FCFS or EDD rule is only used for selecting among large container ships or among medium-sized and small ships. Notice that when a deep-sea container ship is waiting for a free berth, then a small feeder will not be assigned to quay wall even if there is sufficient space for it.

The second step of the berth allocation process is to find a berth at the quay with sufficient space for the ship. Again, there are two alternatives: The *first-fit method* scans the quay from left to right and assigns the ship to the first position, that is large enough. The *best-fit method* scans the entire quay and selects the smallest available space that is large enough for the ship. Obviously, the idea behind the *best-fit method* is to save large spaces for larger container ships that might arrive later.

8.3.4 Performance Measures

The main goal of the simulation model is to determine whether the quay capacity is sufficient for a certain scenario or not. That is, we need measures that describe the utilization of the quay as well as the impact of possible insufficiencies in capacity for the ships and for the terminal. In its current state, the simulation model writes detailed information about ships and events into files, which can then be analyzed using MS Excel. For this study, we determined the following measures.

The **container throughput** is the number of containers discharged and loaded within the horizon of the simulation. Note that this measure is given in TEU (and not boxes).

The **throughput of ships** is the number of ships whereby the handling could be completed within the horizon of the simulation. This measure is given separately for each ship class.

The **average** and **maximum ship waiting time** for a free berth is the average difference between ship arrival and berthing time of the ship. Also these measures are determined separately for each ship class. Note that the average is calculated over all ships and not just for those ships that do not immediately get a berth upon their arrival. In addition, the **standard deviation** of the ship waiting times is reported for each ship class.

The **percentage of waiting ships** is the number of ships that have to wait for a berth divided by the total number of ships. Like the two previous measures, this one is determined separately for each ship class.

The **quay utilization** gives the average percentage of the quay, occupied over time. This percentage quay utilization is determined at every event (*i.e.* ship arrival or departure) during the simulation time. At the end, the average value of these observations is calculated. Note that the safety distance between ships is counted as occupied.

8.4 Experiments

In this section, we present the results of several experiments, which were carried out with the simulation model from the previous section. The purpose is to illustrate typical applications of such a berth simulation and to demonstrate the power of this rather simple model as well as its limitations.

The model was coded in the simulation framework *Flexsim* (see, *e.g.* Garrido (2009)). The experiments were conducted using a PC with Intel Pentium M processor with 2.13 MHz clockpulse and 2 GB RAM, running under Windows XP.

8.4.1 Basic Settings

For the experiments to be presented below, we have derived distributions concerning the interarrival time, ship size and handling time (see Section 8.3.2) from real data provided by a major European container terminal. The year, from which the data has been taken, was a very busy one for this terminal, hence the distributions lead to a considerable but realistic workload. For all experiments the length of the quay has been set to 2,000m.

The standard setting of the berth allocation strategy consists of the *best-fit method* for finding a berth along the quay, the FCFS rule for selecting waiting ships from the queue, and without priority for deep-sea container ships (see Section 19.5). These settings have been varied systematically in order to analyze their impact.

A scenario is defined by a fixed parameter setting (*i.e.* selected workload, selected strategies). Naturally, due to the use of probability distributions and random numbers, different simulation runs for the same scenario will not lead to identical results. Consequently, several simulation runs were carried out for each scenario. In the following, the reported results are averages of the simulation runs of a scenario. Each simulation run covered 90 days, which took on average 110 seconds of CPU time.

8.4.2 Impact of Workload

In a first experiment, we simulated the impact of an increased workload. Such simulations are of high practical relevance for terminals that want to know if the current quay is sufficient for an expected growth in container throughput caused by one or more additional ship services. For this paper, the purpose is to demonstrate how the simulation model can help to analyze such future scenarios.

We have compared two scenarios: one with the original workload according to Section8.4.1 and one with an increased workload. All other distributions and strategy settings were kept unchanged. The increase in workload was achieved by dividing all interarrival times by a constant factor. Hence, the ship sizes and loads remain the same but the number of ships arriving per week increases, as would be the case when additional services are considered. The simulation results are displayed in Table 8.6. For both scenarios, five simulation runs were carried out (five runs were considered to be sufficient for providing an impression of the behavior of the simulation model).

Table 8.6 Simulation results for normal and high workload

	Ship Class	Normal Workload	High Workload
No. of Ships	Feeder	1,084	1,342
	Medium	88	114
	Deep-sea	62	80
Average Waiting Time per Ship [h]	Feeder	4.0	15.5
	Medium	4.8	15.1
	Deep-sea	6.2	17.1
Maximum Waiting Time per Ship [h]	Feeder	40.0	62.1
	Medium	36.1	58.2
	Deep-sea	36.0	60.8
Ships that Have to Wait in Queue	Feeder	31%	73%
	Medium	34%	74%
	Deep-sea	41%	79%
Standard Deviation of Waiting Time per Ship	Feeder	7.3	15.5
	Medium	8.0	15.0
	Deep-sea	8.8	16.0
Total Throughput [TEU]	All	695,996	897,812
Quay Wall Occupation Over Time		64%	80%

The table shows that the TEU throughput increased by about 25%. The number of ships increased accordingly. This led to longer waiting times; they increase from about 5h per ship to about 16h per ship. Also maximum waiting times and the percentage of ships that had to wait for a free berth, increased substantially. Note that these measures reflect the terminal's service quality, and one can see that the workload is too high to allow for an acceptable service quality.

One should take into account that ship waiting times for these scenarios might slightly differ from reality. While the model contains only a simple berth assignment strategy, in practice, better decisions could be made considering the upcoming ship arrivals. Moreover, ships would slow down if they are expecting to wait for a berth. This leads to a later arrival, and hence, a shorter waiting time. It should also be mentioned that we have used the same empirical distributions for the handling speed in both scenarios, that is, we have assumed that the average speed per container remains the same in the high workload case.

It is interesting to note that both the average waiting time and the percentage of waiting ships are highest for deep-sea container ships. This is probably because these are the longest ships – therefore, it takes a longer time until a berth of sufficient length has become free.

The results for the quay wall occupation show that in case of the normal workload only 64% of the quay wall is occupied. Considering that this scenario corresponds to a very busy terminal, it might be surprising that the occupation is not higher. However, the result is in line with the real-world terminal (which indicates that our model shows realistic behavior with regard to quay wall occupation). For the second scenario with substantially higher workload, the occupation of the quay climbs to 80%.

There are several reasons for quay wall occupation rates well below 100%, even in cases of very high workload. Of course, when several ships are mooring along the quay, it is very likely that there are spaces between the ships that are too small for arriving ships. Another effect is that even for the second scenario, with an increased workload, there are times when the queue is empty and thus no ship arrives to make use of available quay capacity. Finally, a large container ship may wait for a berth while there is some free quay capacity that is not yet sufficient, but due to the FCFS strategy smaller ships, which are also waiting, do not get a berth.

Summing up, the simulation model enables the analysis of different workload scenarios with regard to important performance measures that reflect both quay utilization and terminal service quality. This makes it a valuable tool for examining future developments. In practice, of course, there are also other factors that could be incorporated when defining future scenarios. This could be an additional berth or an increased handling speed.

8.4.3 Impact of Strategy Parameters

Another important application of the simulation model is the analysis of the impact of different berthing strategies (see Section 19.5). In a first step, we consider the prioritization of deep-sea container ships. Terminals usually prioritize these ships in a way that they can be processed within a certain time window.

We compare the case without giving priority to deep-sea container ships (hence a pure FCFS strategy) with the case where each deep-sea container ship has a higher priority than medium- and small-sized ships. Table 8.7 shows the simulation results. To keep things concise, we restrict ourselves to the high workload case here because this scenario shows the impact of prioritization more clearly. It should be mentioned that the purpose of this experiment is to demonstrate the capability of our model to appropriately capture the impact of the strategy, however, the scenario itself is not very realistic because of the high workload.

We observe that both the average and the maximum waiting times decrease for deep-sea container ships but increase for the two classes of smaller ships. This is, of course, the effect that could be expected. The percentage of ships that have to wait does not significantly change. It does not decrease for deep-sea container ships because the high workload implies that most arriving ships have to wait for a berth. Also the quay occupation remains the same, but this is because the same distributions were employed for the workload and the container handling speed in both scenarios.

Table 8.7 Simulation results for deep-sea container ship prioritization (high workload case)

	Ship Class	Without Prioritization	With Prioritization
No. of Ships	Feeder	1,342	1,301
	Medium	114	112
	Deep-sea	80	86
average waiting time per ship [h]	Feeder	15.5	26.6
	Medium	15.1	27.7
	Deep-sea	17.1	3.4
Maximum Waiting Time per Ship [h]	Feeder	62.1	90.4
	Medium	58.2	89.2
	Deep-sea	60.8	21.7
Ships that Have to Wait in Queue	Feeder	73%	76%
	Medium	74%	79%
	Deep-sea	79%	79%
Standard Deviation of Waiting Time per Ship	Feeder	15.5	23.5
	Medium	15.0	24.0
	Deep-sea	16.0	3.9
Total Throughput [TEU]	all	897,812	900,044
Quay Wall Occupation Over Time		80%	80%

Next, we examined the impact of the rule that is used to select ships from the queue. We compared the standard setting (FCFS, no ship priority, best fit for berth selection) with a setting in which the FCFS rule was replaced by the EDD rule described in Section 19.5. However, we could not find a significant difference between these two rules.

In the final experiment we tested the influence of the method to determine a berth, *i.e.* a position along the quay. We compared the standard setting with a setting in which the *best-fit method* was replaced by the *first-fit method* (see Section 19.5). Although once again, we did not find a significant difference.

The results of the last two experiments could have two different interpretations: Either replacing the strategy does not have an impact (*i.e.* the strategies are very similar with regard to their behavior), or there are certain limitations in the model that prevent us from detecting actual differences. The latter point will be discussed in the next section.

8.4.4 Limitations of the Model

As outlined above, some of the experiments did not lead to different results for different strategies. One possible reason for this might be that the simulation runs of the same scenario are remarkably different. This could prevent the detection of an impact in the change of strategy if the impact of the change is small.

Consider as an example the five simulation runs of the "normal workload" scenario of Table 8.6. The number of handled containers is largely responsible for the workload. According to Table 8.6, the average throughput was 695,996 TEU in these five runs. But the range of the values was from 627,591 TEU to 793,627 TEU. The standard deviation was 56,595 TEU, which leads to a coefficient of variation of 8.1% (see Bluman (2008)).

This variation is caused by the distributions, especially those of the interarrival times for the deep-sea container ships. Both very small and very large interarrival times have rather small probabilities. But it may happen that in one simulation run an interarrival time of perhaps one week is drawn once or twice, while such extremely large values do not appear in another simulation run. Consequently, the second run will have several more ships than the first one during the same simulation time. Because the deep-sea container ships are associated with a large number of containers to be handled, there is a large impact on the overall workload. Given that the number of large ships in one simulation run is rather small, such effects are not unlikely. In fact, in the five aforementioned simulation runs, the number of deep-sea container ships was between 54 and 73 during the same period of 90 days, although one might argue that one scenario should be (more or less) related to a fixed number of deep-sea container ship arrivals. Note that this problem does not occur for small feeders because they carry fewer containers. They arrive more frequently, and their interarrival time distribution contains less extreme values.

The consequence is that the variation within the simulation runs of one scenario might be higher than the difference between two scenarios that are related to two different strategies. If this occurs, the difference between the two strategies might not be detected.

This issue can be overcome in two ways. The first approach would be to carry out a very large number of simulation runs for each scenario. This would lead to a large sample, which might allow detection of significant differences by means of statistical tests.

The second approach would be to adapt the input data and the model such that the simulation runs of each scenario lead to much less variation. The input data of the model could be improved by thoroughly eliminating outliers before deriving the distributions. The model itself could be improved by replacing the interarrival times for large ships with actual container ship schedules and distributions for delays. Some comments on the latter idea can be found in Section 8.5.1.

8.5 Extensions

As pointed out above, the simulation model of Section 8.3 is a general one that needs to be adapted to a specific terminal. In what follows, we outline the most important generalizations of the model. We discuss the incorporation of container ship schedules, more general quay restrictions, ship handling times based on quay crane availability, and more realistic approaches to berth allocation.

8.5.1 Schedules of Container Ships

The model introduced in Section 8.3 contains interarrival times for all ship classes. In practice, this is appropriate for smaller ships. Large ships, however, arrive according to a fixed schedule. Typically each ship service has a fixed planned arrival time that is the same each week. Hence, to model a specific terminal in a realistic way, the schedule of container ships should be incorporated.

Schedules are usually not accurately met. Due to weather conditions or unexpected ship handling times in previous ports, delays, as well as early arrivals may occur. In the case of the major European container terminal mentioned above, deviations from the planned arrival times are prevalent. An analysis of the data that was used in Section 8.4 revealed that about 61% of the ships arrive within a time window of +/- 12 hours of the scheduled time. Larger delays are common, with about 10% of the ships showing delays of more than 48 hours.

Deviations of this magnitude have a substantial impact on the quay wall occupation over time and must therefore be considered in a simulation: While the schedule may imply a more or less even distribution of ship arrivals, delays might lead to arrivals of several ships during a short time window, such that there may not be sufficient berths during such peak times.

Including container ship schedules and distributions of the deviations from planned arrival times enable simulation studies concerning ship services. The terminal management might, for example, consider an additional service which would be scheduled to arrive on a certain day. Then two scenarios could be simulated: one with the current schedule and one that also includes the additional service. The results would indicate whether the terminal capacities (quay and handling equipment) would be sufficient to handle the additional service or not.

Also recall that incorporating schedules of container ships is advisable from a more theoretical point of view. As outlined in Section 8.4.4, drawing interarrival times does not guarantee realistic arrival pattern for large ships, and it may lead to large variations in the workload. If container ship schedules are used, this effect cannot occur because the arrival pattern will be the same each week, and the impact of delays on the total workload is rather small. Hence, including container ship schedules makes the model more realistic and easier to use in practice, and it helps to create more reliable simulation runs.

8.5.2 Shape and Structure of the Quay

The model described above contains one quay wall along which the berthing conditions are the same everywhere. Therefore, any container ship can moor at any location. This assumption holds viable on many real terminals.

However, there are also many terminals with more than one quay wall, which in itself may vary. That is, a quay wall might be equipped with large quay cranes that can serve any ship whereas another quay wall might have only smaller quay cranes which cannot work on large ships. Also, the water depth along one quay wall might be limited such that only ships with smaller draft can moor there.

Such restrictions can easily be incorporated into the simulation model. Each of the quay walls can be modeled separately, together with the restrictions concerning the ship types, which are allowed to be assigned to a berth there.

8.5.3 Quay Crane Allocation to Ships

One assumption in the modeling approach of Section 8.3 was that the handling time of a ship is derived from the number of containers discharged (loaded) and the handling time per container for the related ship type, based on distributions. This implies that the handling time of a ship is not determined dynamically during the simulation, which means that the number of ships at the terminal at the same time and the number of quay cranes assigned to the ship are not taken into account. This assumption leads to a simple model, which contains the quay as the only explicitly modeled resource.

While this may be sufficient for rough simulation studies, it will be important for many studies to extend the model by considering quay cranes as scarce resources. This is inevitable for studies which not only examine the quay capacity in future scenarios but also the number and types of quay cranes.

Quay cranes can be incorporated as follows. When an arriving ship has been assigned a berth, the simulation model has to decide how many quay cranes are assigned to this ship. Each ship should be associated with a maximal number of quay cranes (typically between one for small feeders and five for large deep-sea container ships). The system tries to assign to the ship the largest possible number of quay cranes up to this limit. Whenever another event (ship arrival or departure) occurs during the simulation, the system has to check and possibly reassign the quay cranes to the ships currently at the quay. This step must reflect the terminal's policy, which usually includes decision rules for situations when less quay cranes are available than would be required to serve all ships optimally.

If quay cranes are modeled explicitly, the user has to adjust the their productivities (*i.e.* containers handled per hour per quay crane), most likely in terms of distributions related to the ship classes. Quay crane productivities are more intuitive to use than the parameters needed to calculate the ship handling time as described in Section 8.3.2. The simulation model also becomes more realistic since the actual handling time then depends on the availability of quay crane resources over time and therefore, also the other ships at the quay.

A typical effect on many terminals is that the productivity per quay crane decreases when more quay cranes are working. This is due to increasing interferences between adjacent cranes (see Schonfeld and Sharafeldien (1985)) as well as the limited size of the transport vehicle fleet (terminal trucks, straddle carriers, automated guided vehicles): if more quay cranes are active, less vehicles can serve a quay crane. This could be covered by a workload-dependent productivity of the quay cranes.

This is particularly beneficial if scenarios with different workloads are compared. A scenario related to the original workload of the input data will produce realistic results given that the input distributions are realistic. However, if the workload is increased by adapting the ship arrival distributions (*e.g.* more ships per week), there will be more time intervals during which the quay is fully occupied. Since quay cranes and other resources tend to be scarce in these situations, the ship handling times will increase. Given that the quay cranes are currently not included, the simulation model does not capture this effect; the underlying assumption is that the handling speed per container is based on the input distributions. One might therefore adapt the ship handling time distributions, but then the effect would be part of the input data rather than determined dynamically by the simulation.

A further extension would be to consider different quay crane types in certain segments of the quay. This leads to restrictions concerning the ship types that are allowed to moor in these segments, see also Section 8.5.2.

8.5.4 Berth Allocation

The methods for berth allocation described in Section 8.3 are straightforward and intuitive, but also very simple. In practice, more detailed methods are necessary. Generally speaking, the simulation model has to capture the actual berthing policy of the terminal under consideration even if this might not be "optimal" in some theoretical sense.

Typical practical requirements and processes include the following: berths might be kept free for container ships which are expected to arrive soon even if there are ships waiting in the queue. Equally important, large ships have a planned berth. Containers for such ships will then be stacked close to the berth, and it is essential that the container ship will be assigned to this berth for efficient loading operations. Some terminals divide the quay into logical berths, and ships are not berthed across two such sections even if it would be possible. Finally, there may be individual priorities for ships, services, and shipping companies, which influence the berthing decisions.

Berth planning and related problem settings have become increasingly popular in the scientific literature. Lim (1998) demonstrates that the basic berth planning problem can be modeled as a two-dimensional strip packing problem as well as captured using a graph representation. Park and Kim (2003) introduce a more detailed and realistic model that includes, among other features, the impact of quay crane capacity on the mooring time of the ships, as well as preference for a berth close to the location of the containers to be loaded. Since a comprehensive literature survey is beyond the scope of this contribution, we refer the reader to the excellent surveys of Steenken et al (2004), Stahlbock and Voß (2008) as well as Bierwirth and Meisel (2010). In fact, simulation models like the one introduced here require a good method for berth optimization, but focusing on the solution quality is quite useless if practical requirements are not included. Also short run times are essential since the berth optimization routine is called many times during a simulation time of several months.

8.6 Conclusions and Impact on Terminal Planning

The simulation model presented in this contribution is a simple tool for evaluating the quay wall occupation at container terminals and the achievable service level for given ship arrival scenarios. Various measures for the service level can be derived from the simulation output, whereby the most important are the average and maximum ship waiting time for an unoccupied berth, as well as the percentage of waiting ships.

It is essential that appropriate distributions of ship sizes, arrival times and handling times are used. These distributions differ considerably between the regions of the world. Consider as an example the main container terminals in the North Sea area. These terminals have a substantial share of feeder ships, which are small enough to transit through the Kiel Canal. Since these feeder ships are associated with a specific arrival behavior and handling speed, they have a significant impact on the terminal throughput. By allowing for the definition of several ship classes, our model can easily be adapted to such specific regional conditions.

An important application of the model is an analysis of future workload scenarios, and particularly, additional ship services. A simulation based on such future scenarios can help to determine the expected service level, as well as the benefit of a possible extension of the quay wall.

The model can also be used to investigate the impact of an increased average handling speed on the terminal's service level. In the current model, scenarios for the ship-related handling speed distributions would have to be developed.

Furthermore, the influence of limited water depth and tides can be examined. The tidal range leads to special arrival patterns for large container ships that cannot enter the port during low tide due to their draft. This is of particular interest to terminals that expect to serve more ships with large draft in the future.

The applications discussed above are important for terminal planning in practice. The list shows that both strategic decisions (such as quay wall extension) and tactical decisions (such as additional ship services) can be supported by our simulation model.

In addition, the simulation model may also serve as a test bed for optimization models and methods for berth planning, which is a more theoretical application. Berth planning is carried out in a dynamic environment which is characterized by uncertain information, such as delays of ship arrivals as well as more or less unpredictable berthing times, in particular. Hence, rather than just running a berth planning method using fixed input information, the method should be incorporated into a simulation model which permanently updates the data.

The simulation model in its current state still leaves several opportunities for future research. Firstly, the model's behavior should be improved in order to achieve a more reliable and realistic output. A starting point would be to replace interarrival times by schedules and distributions of delays for large container ships. Another important extension would be to explicitly incorporate quay cranes with productivities as parameters. This would not only provide the user with intuitive control parameters (*i.e.* quay crane productivities), it would also enable the derivation of berthing times in a more realistic way. Secondly, the model could be adapted to specific terminals by incorporating restrictions such as different quays or special berthing strategies. These extensions would then allow for detailed studies concerning a particular terminal.

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Chapter 9

A Technique to Determine the Right Crane Capacity for a Continuous Quay

Frank Meisel and Christian Bierwirth

Abstract
The length of the quay and the number of quay cranes are crucial determinants for the handling capacity and the service quality of seaport container terminals. The appropriate dimensioning of these two resources is dealt with when the layout and the equipment are planned for a new terminal. For terminals in operation, however, the expansion of existing handling capacity is of particular interest. These terminals have liner services contracted, which must be taken into account when deciding on handling capacity adjustments. In this paper, we describe a technique to determine the quay crane capacity for a terminal with respect to a projected set of liner schedules of calling vessels. For this decision, we take into account the service quality and cost of the terminal that result from crane capacity adjustments. A detailed planning model and a related solution method are presented to anticipate the service operations under different crane deployments. Computational tests are conducted to determine the appropriate number of cranes to deploy at a terminal and to identify the most favorable crane assignment strategy.

9.1 Introduction

The service of vessels at a seaport *C*ontainer *T*erminal (CT) must be executed in a fast and reliable way to satisfy the expectations of vessel operators (see Wiegmans

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J. W. Böse (ed.), *Handbook of Terminal Planning,*
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DOI 10.1007/978-1-4419-8408-1_9,

et al (2001)). In this context, reliability means to realize all container handling operations for a vessel within the projected service time interval as defined by a liner schedule. According to Notteboom (2006), 86% of liner schedule disturbances are caused by unexpected waiting times of vessels before berthing and unforeseen low container handling productivity at a terminal, see Figure 9.1. In other words, insufficient quay space and insufficient handling capacity frequently slow down the service operations.

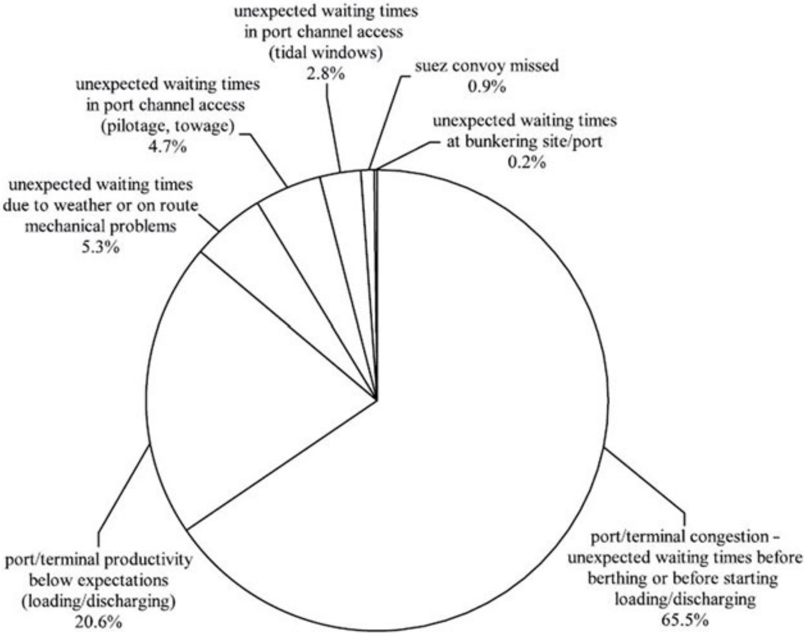

Fig. 9.1 Sources of liner schedule unreliability

When a new terminal is built, much effort is spent on determining an appropriate quay layout and an associated number of *Q*uay *C*ranes (QCs). However, the future demand of handling capacity is usually unknown at this point in time. Therefore, layout and equipment decisions are made on the basis of demand forecasts, using analytical methods like queuing theory or simulation techniques.

In contrast to newly built terminals, the capacity demand of terminals in operation is prescribed by the contracted liner services that are served at the CT. Here, the vessels call cyclically according to the expected arrival times of the liner schedules. Moreover, the container volume that must be handled for a vessel is more or less identical each time it calls at the terminal. A so-called vessel call pattern that describes the projected arrival times of vessels, their container volume, and the approximate handling times is therefore known to the terminal management. This information forms the basis for determining the service plans for the terminal resources. Moreover, it serves as valuable information for medium-term adjustments of the handling capacity of the terminal, such as deciding on increasing or decreasing the number of QCs to deploy at the seaside.

In our paper, we consider terminals with a given vessel call pattern where tactical decisions on the number of cranes to deploy and on the general strategy for assigning cranes to vessels are supported by determining service plans for the seaside resources. This technique enables evaluating tactical decisions by their impact on service quality, handling capacity, and cost of a terminal.

The paper is organized as follows. In Section 9.2 we discuss the relevancy of crane capacity decisions for the competitiveness of a terminal. In Section 9.3, the available studies dealing with the dimensioning of seaside resources of a CT are surveyed. Section 9.4 discusses relevant determinants that should be taken into account when deciding on the crane capacity of a terminal. Section 9.5 provides an optimization model and a solution method for determining an appropriate number of cranes to deploy at a terminal. The approach is computationally tested in Section 9.6. Section 18.5 concludes the paper.

9.2 The Relevancy of Crane Capacity Decisions for Terminal Planning

Deciding on the number of cranes to deploy at the seaside of a terminal impacts both the service quality and the cost structure. The service quality is affected because the more cranes are available for serving vessels, the shorter the handling times of vessels will be. The corresponding cost of a terminal are fixed costs for investments, amortization, etc. and variable costs incurred by operating the cranes. Operating a QC requires a group of laborers, called a gang, which consists of a skilled crane driver, stevedores for the lashing of containers, a foreman which coordinates the operations, and, possibly, a number of drivers for the horizontal transport means. Therefore, putting cranes into operation comes along with considerable labor costs, which is often the primary component of variable terminal costs in industrialized economies. Together, the handling capacity of a terminal, the promised service quality of handling operations, and the costs for deploying and operating the cranes determine major conditions for the vessel service operations, see Figure 9.2. Balancing the effect of these determinants is a necessary prerequisite to achieve the competitiveness for a terminal. The paper follows this lead by determining an efficient crane capacity regarding service quality and cost.

When terminal operators think about deploying more cranes at the seaside, they usually aim at improving service operations and service quality. Nevertheless, this does not mean that costly investments in new equipment are needed in every case. Depending on the particular situation of a terminal, a range of alternatives can be available for the adjustment of crane capacity:

- Quay cranes may be leased to/from neighboring container terminals or quay cranes out of service may be reactivated (see Yi et al (2000)).

- Quay cranes may be flexibly manned by gangs according to the terminal's workload (see Silberholz et al (1991) as well as Meisel and Bierwirth (2005)).

These actions for adapting crane capacities are less expensive compared with infrastructure investments and thus, often preferred by the management. If such alternatives are available at a CT, flexible adjustments of crane capacity on a short- or medium-term basis are possible.

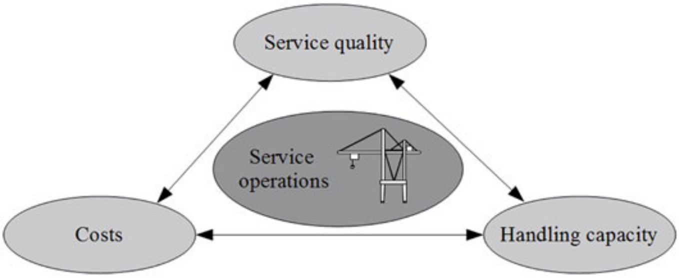

Fig. 9.2 Driving forces of vessel service operations

The number of cranes at a quay impacts the CT management in different ways, because it influences numerous planning problems like the assignment of cranes to vessels, the workforce planning, and the organization of container transport operations between the terminal areas. It can be seen that cranes are a core resource which has a link to almost every transport and handling process at a terminal. Therefore, selecting the number of QCs to deploy at the seaside is a central decision in terminal planning.

9.3 Literature

Studies investigating the appropriate dimensions of CT infrastructures and equipment usually apply queuing theory or simulation models. The choice of an appropriate queuing model for representing CT systems is investigated in the early work of Edmond and Maggs (1978). Queuing models are presented that differ regarding the arrival rate of vessels, the number of processors (berths), and the working rate of the terminal. Different investment options for berths and equipment are evaluated on the basis of these queuing models. While the authors admit that ships operate on scheduled services, the queuing models use randomly distributed arrival times instead of precise schedule information. Moreover, the queuing models do not incorporate the rules used at a terminal for assigning cranes to vessels. Schonfeld and Frank (1984) and Schonfeld and Sharafeldien (1985) propose an advanced queuing model that respects productivity losses caused by crane interference and also take the total costs for berths, cranes, labor, vessels, and cargo into account. On this basis, the number of berths and quay cranes needed at a CT is determined. The queuing model of Daganzo (1990) is used for evaluating different priority rules for assigning cranes to vessels. One rule gives priority to vessels with few holds to be processed. A second rule gives priority to vessels with many holds to be processed. The queuing model demonstrates that the first rule achieves a higher throughput of vessels at the terminal. Still, the models proposed by Schonfeld and colleagues and by Daganzo ignore liner schedules.

Silberholz et al (1991) study the impact of work rules on the productivity of a terminal. Using a simulation model, it is decided on the number of cranes to use for the service of a vessel and on the shift system for staffing the cranes. Like in the previous studies, fixed arrival rates of vessels are used by the simulation, which neglects the impact of liner schedules. Moreover, the vessels are served in first-come first-served manner. In other words, the terminal management merely reacts to vessel arrivals instead of actively planning the service operations for a period as is usually done in practice.

A more detailed simulation model is presented by Legato and Mazza (2001), where berthing space and crane capacity is reserved for so-called primary vessels while secondary vessels are served only in situations of low workload. Dragovic et al (2005) and Dragovic et al (2006) combine simulation techniques and queuing models to evaluate different priority rules for assigning cranes to vessels. Similar to the results of the queuing model of Daganzo (1990), it is found that giving priority to smaller vessels reduces the average port stay time at the expense of large vessels. For various arrival rates, the berth-crane combination is determined that minimizes the total terminal cost as defined by Schonfeld and Sharafeldien (1985).

Allahviranloo and Afandizadeh (2008) plan investments in terminal infrastructure, terminal equipment, and vessel fleets from a macro-economic perspective. The study focuses on deciding on the berthing capacity of terminals with respect to the future development of container traffic. Fuzzy integer programming is used to find the number and type of berths to be constructed within a horizon of about 20 years. Crane capacity decisions are, however, not in the focus of this investigation.

The literature survey shows that the appropriate dimensioning of berth and crane capacity in a CT has been investigated for a long time. Many papers study investment decisions and deployment strategies regarding berths and cranes. So far unconsidered, however, is an evaluation of capacity decisions for a terminal under a projected *V*essel *C*all *P*attern (VCP).

9.4 Drivers of Crane Capacity Decisions

In this paper, we consider a terminal that has a set of contractual agreements with vessel operators. These contracts constitute the VCP of vessels calling at the terminal for being served. The task is to decide on the appropriate number of cranes to deploy at the seaside in the medium term. This decision is evaluated on the basis of the resulting quality of the services and the cost incurred. For this purpose, we assess the tactical decision on the number of cranes to deploy by its impact on the quality of services provided to the vessels in the VCP. To get insight into the resulting service operations, the following drivers of crane capacity decisions and crane capacity utilization will be discussed next:

- the schedule of liner services calling at the terminal,
- the seaside layout of the terminal,
- the crane assignment strategy of the terminal,
- the productivity rate of quay cranes at the terminal, and
- the types of cost affected by the decisions made.

9.4.1 Liner Service Schedules

Container vessels operate in so called liner services. In a liner service, vessels follow a fixed schedule that gives the order of ports to visit and the calling times (see Ronen (1983)). Vessels calling at a terminal according to liner service schedules determine the workload for the terminal resources within a period. More precisely, expected times of arrival and departure, *i.e.* expected times for starting and finishing the service of vessels, are contracted between the terminal management and the vessel operators. This information is used by the terminal to decide on the berthing time of every vessel and on the berthing position at the quay. The obtained service plan is usually referred to as the berth plan. Figure 9.3a illustrates an example for a terminal with a quay of 600m length where five vessels have to be served within the planning horizon. The service process of each vessel is represented by a rect-

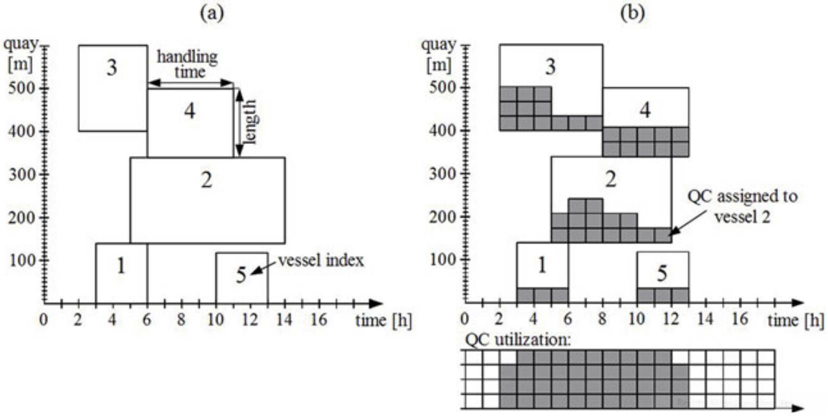

Fig. 9.3 Service plan (a) complemented by a crane assignment (b)

angle. The height of a rectangle corresponds to the length of the vessel (including clearance) and the width corresponds to the projected handling time.

In general, best service quality is achieved if the service of a vessel takes place completely within the time window determined by its expected times of arrival and departure. Obviously, if time windows of different liner services overlap, multiple vessels must be served simultaneously at the quay. To avoid congestions at the seaside of a terminal, vessels may be speeded up on their journey to the terminal in order to realize an earlier arrival. Alternatively, the service must be postponed which leads to a delayed departure. In both cases, penalty costs have to be paid by the terminal for violating the agreements and compensating the additional cost of the vessel operators.

The schedule of liner services is certainly the most important determinant for the crane capacity needed at the quay. In general, the more demanding the liner schedules are the more cranes should be deployed at the seaside to ensure that the required service levels are reached.

9.4.2 Seaside Layout

The utilization of the quay crane capacity provided at a terminal depends on the number of vessels served at the terminal simultaneously as well as on the flexibility in moving cranes from one vessel to another. These two factors are basically determined by the seaside layout of a terminal. According to Imai et al (2005) and Bierwirth and Meisel (2010) the following layout types are distinguished:

- *Discrete layout*: The quay is partitioned into a number of sections, called berths. Only one vessel can be served at each single berth at a time. The partitioning can either follow the construction of the quay (see Figure 9.4a) or is organizationally prescribed to ease the planning problem (see Figure 9.4b).
- *Continuous layout*: There is no partitioning of the quay, *i.e.* vessels can berth at arbitrary positions within the boundaries of the quay (see Figure 9.4c). For a continuous layout, berth planning is more complicated than for a discrete layout at the advantage of better utilizing quay space.
- *Hybrid layout*: Like in the discrete case, the quay is partitioned into berths, but large vessels may occupy more than one berth (see Figure 9.4d) while small vessels may share a berth (see Figure 9.4e). An indented berth results if two opposing berths exist, which are used to serve a large vessel from both sides (see Figure 9.4f).

In the following, we consider a terminal with a continuous layout (Figure 9.4c), where vessels can be berthed arbitrarily provided enough quay space is available. In such a terminal, the rail mounted quay cranes can be assigned in various constellations to the vessels served in parallel (see Figure 9.5). This provides flexibility for high utilization of the QC resource. Therefore, the investigation of the tactical

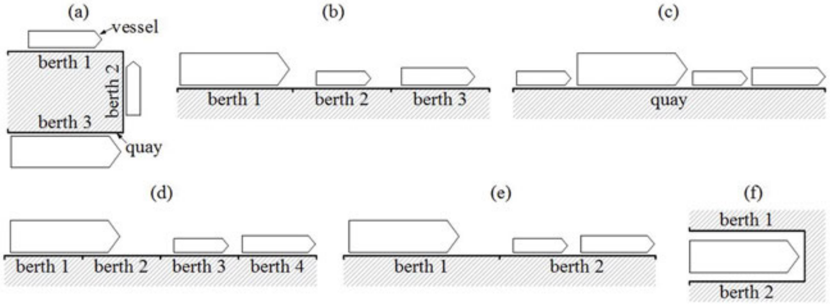

Fig. 9.4 Berth and quay relationship

decision on the number of cranes to deploy appears to be of particular importance for the service operations at a continuous quay.

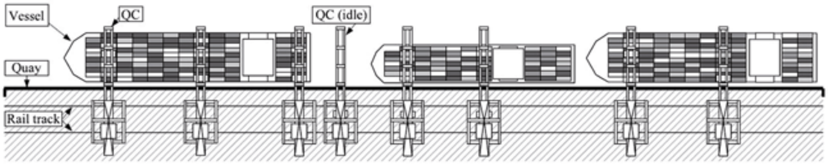

Fig. 9.5 Vessels served simultaneously at a continuous quay

9.4.3 Crane Assignment Strategies

To provide high service quality, the terminal management is responsible for assigning sufficient crane capacity to vessels such that the projected departure times are met. When assigning cranes to vessels, the volume of containers to be loaded and unloaded is taken into consideration. This volume is usually transferred into a crane capacity demand of a vessel by calculating the number of QC hours required to fulfill the service operations. Then, the terminal management assigns a crane capacity to the vessel that meets this demand.

Figure 9.3b shows a possible crane capacity assignment for the service plan shown in Figure 9.3a with four cranes available at the quay. A gray shaded rectangle within a vessel rectangle indicates the assignment of one QC in the corresponding time period. As can be seen in this example, assigning more cranes to a vessel can accelerate its handling time at the expense of other vessels. For example, the finishing of Vessel 2's service is projected at time 14 in Figure 9.3a whereas it is already completed at time 12 under the crane assignment shown in Figure 9.3b. The finishing time of Vessel 3, however, increases from time 6 to time 8 as a result of the crane assignment. It is obvious that crane assignment decisions have an impact on the service operations and hence, on the service quality offered by the terminal. A typical constraint for the crane assignment is that the number of cranes serving a vessel simultaneously is restricted. A maximum number of cranes represents a technical limit whereas a minimum number of cranes can be contracted between the vessel operator and the CT operator. If the minimum number of cranes is larger or equal to one, a vessel is served without preemption. Chu and Huang (2002) provide empirical data for different terminals of the port of Kaohsiung (Taiwan), which reveals that the majority of vessels is served by two to three QCs while large vessels can be served by up to six cranes in parallel.

The assignment of cranes to a single vessel is called a *QC-to-Vessel assignment*. Basically, a terminals management chooses one out of two strategies for generating QC-to-Vessel assignments:

- The number of cranes assigned to a vessel is kept fixed throughout the service process, which is referred to as a *time-invariant assignment* (see Vessels 1, 4, and 5 in Figure 9.3b).
- In a *variable-in-time assignment*, the number of cranes assigned to a vessel can change during the handling time (Vessels 2 and 3 in Figure 9.3b).

The exclusive consideration of time invariant assignments eases the distribution of cranes to vessels substantially. Nevertheless, variable-in-time assignments can increase the service quality because they create more flexibility regarding the distribution of cranes to vessels. For example, a variable-in-time assignment allows removing cranes from a vessel before the service is completed in order to serve another vessel of higher priority. Chu and Huang (2002) report that crane ready times differ by more than one hour for 50% of the large vessels in practice, *i.e.* variable-in-time QC-to-Vessel assignments are realized frequently.

The crane assignment strategy used at a terminal should be taken into account when deciding on the cranes to be deployed. Quite generally, time-invariant assignments will call for a larger number of cranes to reach a desired service level.

9.4.4 Quay Crane Productivity

When deciding on the quay crane capacity also the container handling productivity achieved by the cranes is of relevance. Typically, cranes do not achieve the technically possible productivity due to productivity losses caused by operational disturbances. We consider two potential sources of productivity losses:

- QCs interfere each other during the service of a vessel.
- The vessel is berthed apart from its desired berthing position.

Since QCs are rail mounted they are unable to pass each other. As a consequence, interference among QCs can lead to unproductive crane idle time. In general, the more cranes are assigned to a vessel the more interference will take place. This leads to a reduction of the marginal crane productivity. This productivity loss can be formally described by an interference exponent (see Schonfeld and Sharafeldien (1985)). For a given interference exponent α $(0 < \alpha \leq 1)$, the productivity obtained from assigning q cranes to a vessel for one hour is given by a total of q^{α} QC hours. Crane interference increases when cranes must operate under congestion, *e.g.* due to a clustering of containers to handle within an area of a few vessel bays or if high safety margins between adjacent cranes are prescribed by the terminal management. In such situations, the resulting productivity loss will be reflected by setting α to a low value. An interference exponent has been applied by Silberholz et al (1991) to support the allocation of human resources in container terminals and by Dragovic et al (2006) for a simulation study on the berthing process. Empirical data indicates that α is about 0.93 in practice (see Chu and Huang (2002)). Figure 9.6a illustrates the effect of different values of α on the productivity of crane capacity.

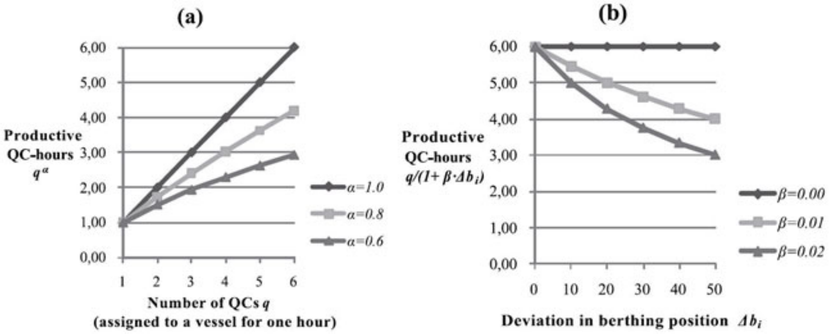

Fig. 9.6 QC productivity effects – interference (a) and apart berthing (b)

The productivity of a terminal is also affected by the workload of horizontal transport means. This workload is minimized if a vessel berths at its desired berthing position. If the actually chosen berthing position of a vessel is apart from the desired position, the load for the horizontal transport increases. This effect can be partially alleviated by deploying more transport vehicles. However, a larger number of vehicles decelerates the average speed and thus, reduces the service rate again. Therefore an apart berthing position of a vessel leads to a productivity loss for the cranes. This productivity loss can be modeled by an increase in the vessel's QC capacity demand. Let β denote the relative increase of QC capacity demand per unit of berthing position deviation, called the berth deviation factor. Hence, when a vessel i requires m_i QC hours of its service but it is positioned Δb_i quay segments away from its desired berthing position b_i^0, at least $(1+\beta\cdot\Delta b_i)\cdot m_i$ QC hours must be assigned to compensate the productivity loss. The appropriate value for the parameter β depends on the capacity of the horizontal transport system. If the transport system is known to be a bottleneck in the terminal operation, β must be set to a high value in order to reflect the considerable crane productivity loss that follows from overstraining the transport system by berthing vessels apart from their desired positions. Figure 9.6b illustrates the effect of different values of β and Δb_i on the productivity of crane capacity if six cranes serve a vessel simultaneously.

Both effects, crane interference and apart berthing, should be taken into consideration when deciding on the number of cranes to deploy at a terminal. In this approach, low values of α and high values of β reflect high productivity losses. These losses may be compensated in turn by deploying more cranes at a terminal. However, also a counter effect is observed because with an increasing number of cranes, productivity losses caused by crane interference increase as well.

9.4.5 Cost Types

With regard to the competitiveness of a terminal, crane capacity decisions should be made carefully, reflecting their impact on the service quality of vessels and the cost of a terminal. To bring together service quality and terminal cost, quality must be assessed by cost rates. A perfect quality is reached if a vessel is completely served in the time span between its *E*xpected *T*ime of *A*rrival (ETA) and its *E*xpected *F*inishing *T*ime (EFT). Violations of this time window lead to penalty costs for the terminal operator. In the following, three types of cost are considered for assessing the service quality provided to a vessel:

- Speedup costs arises, if the vessel must catch a berthing time earlier than ETA.
- Tardiness costs arises, if the service exceeds the EFT.
- A fixed penalty arises, if the service exceeds a *L*atest *F*inishing *T*ime (LFT).

The corresponding cost rates are given as c^1, c^2, and c^3. Speedup costs and tardiness costs grow constantly in time, which means that the higher the required speedup (tardiness), the higher the speedup costs (tardiness costs) will be. These cost rates can be used, *e.g.* to account for increased fuel consumption when vessels must travel at high speed to catch early berthing times at the terminal (see Park and Kim (2003)). In practice, fixed penalty costs are often additionally contracted. It has to be paid by the terminal operator if the departure of the vessel is beyond its LFT. Note that not every of the above cost types must be of interest for a terminal, *e.g.* if no compensation is contracted for speedups. In such a situation, the corresponding cost type can be removed from consideration by setting its cost rate to zero in the subsequently presented optimization model.

Service quality costs of vessels can be reduced by deploying a large number of QCs at a terminal. Nevertheless, operating QCs leads to high costs for the labor force, energy, maintenance and so on. Furthermore, the effort may not pay off, if the productivity of cranes decreases substantially due to interference. For this reason, the CT management should also take the costs for manning QCs into account when deciding on the number of cranes to put into service. To combine service quality objectives and resource cost objectives, a fourth cost type is included in the consideration. The QC operating costs evaluates the number of hours QCs are utilized in order to serve the vessels. The resource cost objective accounts for the decreasing marginal productivity of QCs and the resulting trade-off between accelerating the handling of a vessel and the operating costs for cranes. The cost rate per QC hour is denoted as c^{oper}. The sum of service quality costs of vessels and operating costs of cranes is called the *service costs* of a CT.

When deciding on the number of cranes to deploy at a terminal, not only the variable costs but also fixed costs for the cranes are of relevance to obtain an economic sound solution. Fixed costs of cranes must be paid independent of the operational utilization of the equipment. These costs may include insurance, depreciation, and others. Without considering the composition in detail, we assume that fixed costs incur at a rate c^{fix} per crane.

9.5 Joint Planning of Crane Deployment and Service Operations

In order to decide on the number of cranes to deploy at the seaside of a terminal, we formulate a mathematical optimization model and provide powerful solution methods. The model has been proposed first in Meisel and Bierwirth (2009). It generates service plans for the liner services calling at the terminal by deciding on the berthing position, the berthing time, and the number of cranes that serve a vessel (see Figure 9.3b for an example). It incorporates all the effects described in the previous section. The model is extended here, such that the number of cranes to deploy at the terminal is subject of the decision making instead of a given and fixed parameter. The pursued objective is to minimize the total costs that arise for deploying cranes, operating cranes, and the service quality costs of vessels.

9.5.1 Assumptions

1. The cranes are considered identical, *i.e.* they show the same maximum handling productivity and every crane has the technical capability to serve every vessel.
2. It takes no time to move a QC from one vessel to another vessel.
3. It takes no time to berth and to un-berth vessels.
4. Each quay position shows sufficient water depth to berth every vessel.

9.5.2 Notation

Input data:

V set of vessels (liner services) calling at the terminal, $V = \{1, 2, \ldots, n\}$,
L number of 10-m berth segments (length of the quay),
T set of 1-hour periods, $T = \{1, 2, \ldots, H\}$, H is the planning horizon,
l_i length of vessel $i \in V$ given as a number of 10-m segments,

b_i^0	desired berthing position of vessel i,
m_i	crane capacity demand of vessel i given as a number of QC hours,
r_i^{max}	maximum number of QCs allowed to serve vessel i simultaneously,
R_i	feasible range of QCs assingable to vessel i, $R_i = [1, \ldots, r_i^{max}]$,
ETA_i	expected time of arrival of vessel i (as predicted by its liner schedule),
EST_i	earliest starting time if journey of vessel i is speeded up, $EST_i \leq ETA_i$,
EFT_i	expected finishing time of vessel i (contracted with the vessel operator),
LFT_i	latest finishing time of vessel i without penalty costs arising,
c_i^1, c_i^2, c_i^3	service cost rates for vessel i given in units of 1,000\$ per hour,
c^{oper}	operating cost rate given in units of 1,000\$ per QC hour,
c^{fix}	fixed costs per QC within the planning horizon given in units of 1,000\$,
α	interference exponent,
β	berth deviation factor,
M	a large positive number.

Decision variables:

Q	integer, number of QCs to deploy at the terminal,
b_i	integer, berthing position of vessel i,
s_i	integer, time of starting the handling of vessel i (berthing time),
e_i	integer, time of ending the handling of vessel i (finishing time),
r_{it}	binary, set to 1 if at least one QC serves vessel i at time t, 0 otherwise,
r_{itq}	binary, set to 1 if exactly q QCs serve vessel i at time t, 0 otherwise,
Δb_i	integer, deviation between the desired and the actually chosen berthing position of vessel i, $\Delta b_i = \lvert b_i^0 - b_i \rvert$,
ΔETA_i	integer, required speedup of vessel i to reach its berthing time, $\Delta ETA_i = (ETA_i - s_i)^+$,
ΔEFT_i	integer, tardiness of vessel i, $\Delta EFT_i = (e_i - EFT_i)^+$,
u_i	binary, set to 1 if the finishing time of vessel i exceeds LFT_i, 0 otherwise,
y_{ij}	binary, set to 1 if vessel i is berthed below of vessel j, *i.e.* $b_i + l_i \leq b_j$, 0 otherwise,
z_{ij}	binary, set to 1 if handling of vessel i ends not later than handling of vessel j starts, 0 otherwise.

Figure 9.7 illustrates the interrelations of the so far introduced data and variables for a vessel $i \in V$ in case that it must wait before the service starts ($s_i > ETA_i$) and in case that the vessel is speeded up on the way to the terminal to catch a berthing time ($s_i < ETA_i$).

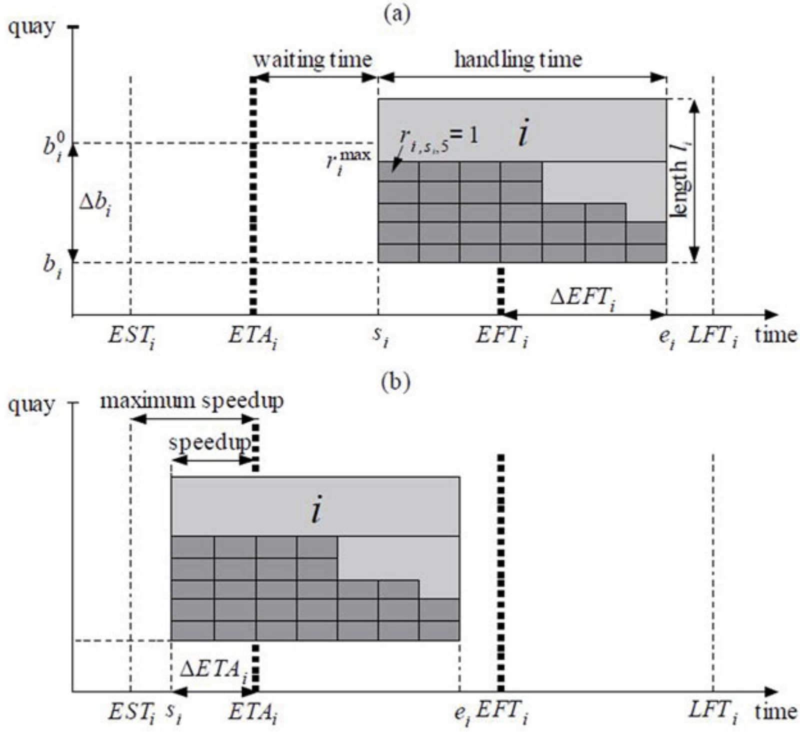

Fig. 9.7 Vessel data – waiting before berthing (a) and speedup case (b)

9.5.3 Optimization Model

The following objective function (9.1) minimizes the total costs arising at a terminal for deploying cranes and for handling liner services with respect to speedup costs, tardiness costs, penalty costs, and variable costs for operating cranes.

$$\min \mathrm{Z} =$$

$$c^{fix} \cdot Q + \sum_{i \in V} \left(c_i^1 \cdot \Delta ETA_i + c_i^2 \cdot \Delta EFT_i + c_i^3 \cdot u_i + c^{oper} \cdot \sum_{t \in T} \sum_{q \in R_i} (q \cdot r_{itq}) \right) \quad (9.1)$$

subject to

$$\sum_{t \in T} \sum_{q \in R_i} (q^\alpha \cdot r_{itq}) \geq (1 + \beta + \Delta b_i) \cdot m_i, \qquad \forall i \in V \qquad (9.2)$$

$$\sum_{i \in V} \sum_{q \in R} (q \cdot r_{itq}) \leq Q, \qquad \forall t \in T \qquad (9.3)$$

$$\sum_{q \in R_i} r_{itq} = r_{it}, \qquad \forall i \in V, \forall t \in T \tag{9.4}$$

$$\sum_{t \in T} r_{it} = e_i - s_i, \qquad \forall i \in V \tag{9.5}$$

$$(t+1) \cdot r_{it} \leq e_i, \qquad \forall i \in V, \forall t \in T \tag{9.6}$$

$$t \cdot r_{it} + H \cdot (1 - r_{it}) \geq s_i, \qquad \forall i \in V, \forall t \in T \tag{9.7}$$

$$\Delta b_i \geq b_i - b_i^0, \qquad \forall i \in V \tag{9.8}$$

$$\Delta b_i \geq b_i^0 - b_i, \qquad \forall i \in V \tag{9.9}$$

$$\Delta ETA_i \geq ETA_i - s_i, \qquad \forall i \in V \tag{9.10}$$

$$\Delta EFT_i \geq e_i - EFT_i, \qquad \forall i \in V \tag{9.11}$$

$$M \cdot u_i \geq e_i - LFT_i, \qquad \forall i \in V \tag{9.12}$$

$$b_j + M \cdot (1 - y_{ij}) \geq b_i + l_i, \qquad \forall i, j \in V, i \neq j \tag{9.13}$$

$$s_j + M \cdot (1 - z_{ij}) \geq e_i, \qquad \forall i, j \in V, i \neq j \tag{9.14}$$

$$y_{ij} + y_{ji} + z_{ij} + z_{ji} \geq 1, \qquad \forall i, j \in V, i \neq j \tag{9.15}$$

$$s_i, e_i \in \{EST_i, \ldots, H\}, \qquad \forall i \in V \tag{9.16}$$

$$b_i \in \{0, 1, \ldots, L - l_i\}, \qquad \forall i \in V \tag{9.17}$$

$$\Delta ETA_i, \Delta EFT_i \geq 0, \qquad \forall i \in V \tag{9.18}$$

$$r_{itq}, r_{it}, u_i, y_{ij}, z_{ij} \in \{0, 1\}, \qquad \forall i, j \in V, \forall t \in T, \forall q \in R_i \tag{9.19}$$

$$Q \geq 0, \text{ integer.} \tag{9.20}$$

Constraints (9.2) ensure that every vessel receives the required QC capacity with respect to productivity loss from QC interference and the chosen berthing position. Constraints (9.3) enforce that the projected number of deployed cranes Q is respected in every period. In every period, a certain number of QCs is assigned to every vessel which is either zero or taken from the range R_i. A consistent setting of the corresponding variables r_{it} and r_{itq} is ensured by (9.4). Constraints (9.5), (9.6), and (9.7) set the starting times and ending times for serving vessels without preemption.

Constraints (9.8) to (9.11) determine the deviations from the desired berthing position, expected arrival time and expected finishing time for each vessel. Ending the handling of a vessel later than LFT_i is indicated by variable u_i as defined in (9.12). Constraints (9.13) and (9.14) set the variables y_{ij} and z_{ij} which are used in Constraints (9.15) to avoid a simultaneous occupation of the same quay space by two or more vessels.

By Constraints (9.16), the arrival of a vessel can be speeded up to at most the earliest starting time EST_i and the planning horizon H defines a limit on the departure time of the vessels. Constraints (9.17) ensure that each vessel is positioned within the berth boundaries. The further constraints define domains for the remaining decision variables.

9.5.4 Solution Methods

Several heuristic solution methods for the problem stated in Section 9.5.3 are provided by Meisel and Bierwirth (2009).

- A heuristic to construct a feasible berth plan from a priority list of vessels.
- A procedure for locally refining a berth plan by resource leveling.
- A procedure for locally refining a berth plan by shifting clusters of vessels.
- Two meta-heuristics, namely Squeaky Wheel Optimization and Tabu Search, that manipulate the priority list of vessels used by the construction heuristic.

In a number of computational tests, *S*queaky *W*heel *O*ptimization (SWO) has been identified as the best performing solution method. The general concept of SWO, as introduced by Clements et al (1997), is to analyze a solution with regard to the performance of its problem elements. In order to strengthen the overall performance, weak performing elements are assigned higher priority in the solution process by moving them towards the top of a priority list. The new list serves to build a new and hopefully better solution.

For the problem stated in Section 9.5.3, SWO builds an initial solution on a *first-come first-served* basis of the vessels, by applying the construction heuristic. The solution is improved by applying the local refinement procedures. SWO then identifies weak performing vessels by calculating the individual service quality costs of every vessel in a problem. The priority of these vessels is increased at the expense of vessels with lower service quality costs. For this purpose, vessels are sorted in a priority list in the order of decreasing service quality costs. The new priority list is used to construct a new solution and so on. The SWO procedure terminates after analyzing 200 solutions without finding a new best solution. We refer to Meisel and Bierwirth (2009) for a more detailed description of the solution methods.

The described procedure computes a near optimal berth plan for a given number of cranes Q. To identify the right number of cranes to deploy at a terminal, the procedure is repeated for a practical range of different values of Q.

9.6 Computational Study

Three tests are conducted to evaluate the proposed approach for tactical quay crane capacity decisions. The first test addresses the central question of the paper: How many cranes should be deployed at a terminal in order to achieve an economic sound trade-off between service quality and cost of a terminal? The second test investigates the impact of two general strategies for assigning QCs to vessels, namely time-invariant crane assignments and variable-in-time crane assignments as described in Section 9.4.3. The third test investigates the interdependency of the available quay space and the deployed QCs on the service quality of the terminal.

For the tests, we use ten problem instances which have been generated randomly. It must be noted that the vessel data and the cost parameters that are used in the tests do not stem from a practical terminal case. Instead, we set the parameters to values that are frequently used in studies investigating CT planning problems (see, *e.g.* Park and Kim (2003)). It is assumed that the chosen values reflect the relative importance of different cost types and parameters, which is their main role for testing our approach.

Each of the instances contains liner schedules for 40 vessels that arrive at the terminal within one week. 60% of the vessels belong to the feeder class, 30% belong to the medium class, and 10% belong to the jumbo class, *i.e.* there are 24 feeder vessels, 12 medium class vessels, and 4 jumbo vessels considered in each test instance. The liner schedules are represented by expected times of arrival ETA_i of vessels, which are drawn from a uniform distribution of integer values in the interval $U[1,168]$. The planning horizon H is set to ten days (240 hours) to ensure that the complete service of late arriving vessels is covered in the problem. The vessel classes differ in technical specifications and cost rates as shown in Table 9.1. The given ranges for drawing parameters l_i and m_i are in accordance with empirical data provided by Anonymous (2003).

Table 9.1 Technical specifications and cost rates for different vessel classes

Class	l_i	m_i	c_i^1	c_i^2	c_i^3
Feeder	U[8,21]	U[5,15]	1	1	3
Medium	U[21,30]	U[15,50]	2	2	6
Jumbo	U[30,40]	U[50,65]	3	3	9

The maximum number of cranes r_i^{max} for vessel i is determined by dividing the vessel length l_i, which is given in units of 10-meter segments, by a value of 7.5. The obtained value is rounded to the nearest integer value. It is interpreted as the number of cranes that can operate at a vessel with a least inter-crane clearance of 75m, as is a typical safety margin found in practice. The chosen settings for parameters m_i and r_i^{max} ensure that a broad range of vessels is considered in the instances. Assumed that a QC can handle about 30 moves per hour, the generated data represents vessels that require between 150 and 1,950 container moves for being served. Depending on the number of assigned cranes, handling times range from two hours for small feeders to up to two days for jumbo vessels. Figure 9.8 illustrates the VCP for one test instance. It distinguishes the calling vessels by their class and day of arrival. The figure shows that the workload at a terminal is not uniform over the days of a week. In this example, workload peaks are observed at days 4 and 6, where one jumbo vessel and a considerable number of medium vessels arrive. At the other days, either a low number of vessels arrive or mostly feeder vessels call.

The setting of further vessel data like earliest starting times EST_i, expected finishing times EFT_i, latest finishing times LFT_i, and desired berthing positions is done as described in Meisel and Bierwirth (2009). The cost rate per QC hour is set to $c^{oper} = 0.2$ thousand \$. The parameters describing the productivity of cranes are set to $\alpha = 0.93$ and to $\beta = 0.01$, which is in accordance with empirical data provided in Chu and Huang (2002). The latter effects a 1% increase in the handling effort per quay segment of berthing position deviation. The length of the terminal's quay is 1,000m, *i.e.* we set $L = 100$.

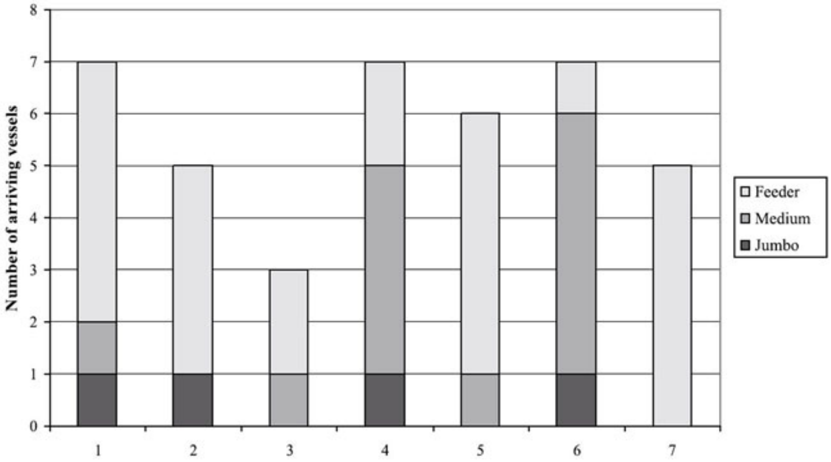

Fig. 9.8 Example of a vessel call pattern

9.6.1 The Number of Cranes to Deploy at the Quay

In a first test, we identify the appropriate number of cranes to deploy at a terminal for the ten problem instances. We solve every of these instances once for $Q = 8, 9, \ldots, 18$ cranes using the SWO method described in Section 9.5.4. The solutions are assessed by total costs Z for deploying cranes, operating cranes, and service quality as calculated by Eq. (1). Figure 9.9 illustrates the average costs observed for the ten instances. The different curves refer to fixed costs rate c^{fix} varied in $[0, 2, \ldots, 10]$. The grey shaded values represent the minimum costs observed under a certain cost rate c^{fix}.

The computational results reveal that a small number of cranes at the terminal leads to very high cost under every setting of c^{fix}. In this case, the crane capacity is insufficient to fulfill the service quality expectations of vessel operators, leading to unacceptable costs for delayed vessel departures. In such a situation, every crane additionally deployed at the quay decreases service costs at a substantial rate. However, total costs decrease at decreasing rate. This illustrates that scarcity of quay crane capacity becomes less relevant for achieving high service quality the more cranes are deployed at the quay.

Figure 9.9 reveals that the number of cranes to deploy for achieving minimum costs depend on the cost rate c^{fix}. In the absence of fixed costs for cranes ($c^{fix} =$

0) 13 QCs should be deployed at the terminal. This crane capacity leads to the best service quality that can be achieved by the terminal under ceteris paribus conditions. Since cranes are deployed at no fixed costs here, larger numbers of cranes lead to the same total costs Z.

Non-zero fixed costs always effect a minimum of the cost function. In other words, in the considered scenarios, we can always compute an optimal number of cranes. *E.g.* when fixed costs are 6,000 \$ per crane in the planning horizon ($c^{fix} = 6$), the number of cranes leading to minimum total costs are $Q = 12$. When turning to $Q = 13$, service costs decrease by 5 (as found from $Z_{12} - Z_{13} = 296 - 291 = 5$ when considering curve $c^{fix} = 0$) whereas fixed costs increase by $c^{fix} = 6$. In general, deploying an additional crane at the seaside is favorable if the decrease in service costs compensate the fixed costs of the crane, *i.e.* if $Z_Q - Z_{Q+1} \geq c^{fix}$ holds, where Z_Q and Z_{Q+1} are the service costs if Q and $Q+1$ cranes operate at the terminal. This effects that the higher c^{fix} the fewer cranes are optimally deployed, where a decreased service quality is accepted for economic reasons.

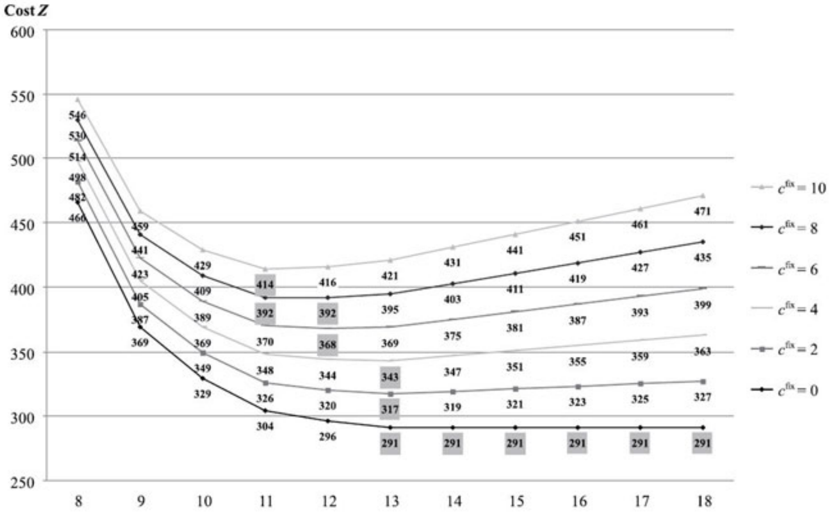

Fig. 9.9 Impact of deployed cranes Q and cost rate c^{fix} on total costs

An interesting case is the situation $Z_Q - Z_{Q+1} = c^{fix}$, where the fixed costs for deploying crane $Q+1$ are identical to the achieved decrease in service costs. Here, the terminal observes identical total costs when deploying Q or $Q+1$ cranes, see the costs of 392 reported for $c^{fix} = 8$ under $Q = 11$ and under $Q = 12$ in Figure 9.9. In such a situation, a terminal should deploy $Q+1$ cranes because a better service quality is achieved at no additional cost. The test illustrates how the presented technique identifies the right crane capacity for a terminal with given liner schedules to be served.

9.6.2 The Impact of Crane Assignment Strategies

The second test investigates the impact of the crane assignment strategy applied at a terminal. A terminal can basically choose between variable-in-time and time-invariant crane assignments for the vessels. In the previous tests, variable-in-time assignments have been allowed, which, in general, lead to better service quality. In practice, however, time-invariant assignments may be preferred to ease the decision process. To identify the change in service quality and cost that follows from the exclusive consideration of time-invariant assignments, we repeat the computations conducted for the previous test under a time-invariant crane assignment strategy. For this purpose, the methods described in Section 9.5.4 are modified to assign a *fixed* number of QCs to a vessel during its whole handling interval.

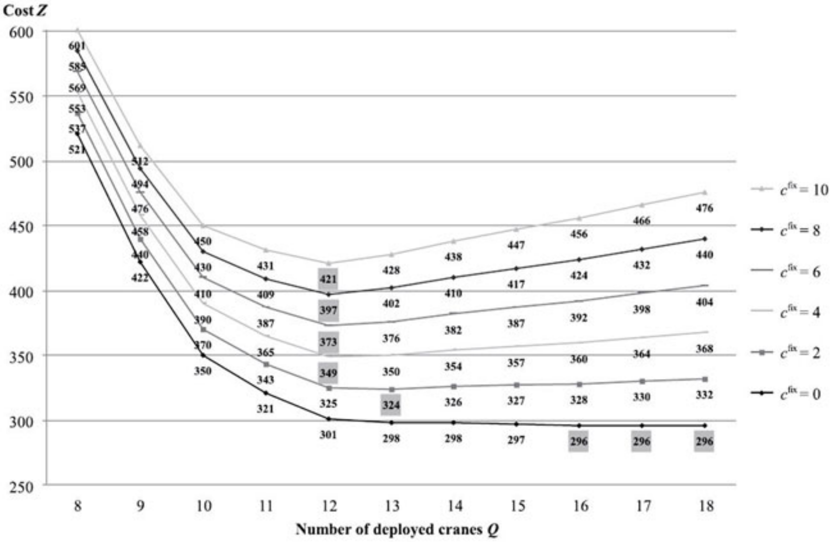

Fig. 9.10 Total costs under time-invariant crane assignments

Figure 9.10 shows the average costs of the ten instances when time-invariant crane assignments are used at a terminal. It can be seen that the inflexible crane assignment strategy leads to higher costs compared to the results in Figure 9.9 where variable-in-time assignments are allowed. For a small number of cranes deployed at the terminal, service costs are more than 10% larger compared with the flexible assignment strategy. However, even for a large number of cranes costs are significantly higher than in Figure 9.9. The results reveal that the inflexible crane assignment strategy can call for a higher number of cranes at the terminal. *E.g.* for $c^{fix} = 10$, the optimal number of cranes to deploy is $Q = 12$, while under variable-in-time assignments $Q = 11$ led to minimum total costs for the terminal.

9.6.3 The Interdependency of Quay Crane Capacity and Quay Space Capacity

In a third test, we investigate the interdependency of the two resources quay space and quay cranes. While this paper addresses the crane capacity decisions, the available quay space is also a crucial factor impacting the offered service quality. For example, in the previous tests, service quality could not be improved any further when exceeding the optimal number of cranes whereas an additional extension of the quay space could justify the deployment of more cranes for improving services. Due to this interdependency, the capacity of both resources must be well balanced to achieve an optimal utilization of space and cranes. To get an idea of this balancing, we solve the test instances under varied number of deployed cranes $Q = 8, 9, \dots, 18$ and varied quay length of 800, 900, …, 1,500m, *i.e.* L is set to 80, 90, …, 150, respectively. Figure 9.11 shows the average service costs for the ten problem instances for every combination of cranes and quay length.

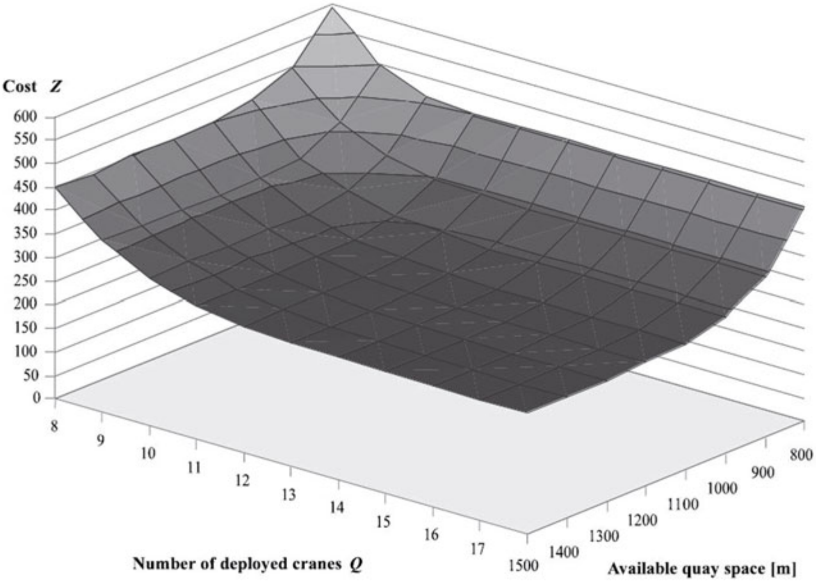

Fig. 9.11 Interdependency of crane capacity and quay space capacity

For reasons of simplicity, fixed costs for deployed cranes and for extending the quay are neglected here. Also the berth deviation factor β, which may take different values for different lengths of the quay, is kept constant at a value of 0.01. The results show that a certain service level can be achieved by different combinations of quay space capacity and QC capacity, which means that, to a certain extent, quay space can be substituted by quay cranes and vice versa. In order to achieve best service quality, both resources must be available at a sufficient level. Otherwise, the respective bottleneck resource drastically limits the service quality. The minimum costs in Figure 9.11 are observed when at least 14 cranes and at least 1,300m of quay space are available. In this situation best service quality is provided to the vessels.

9.7 Conclusions

In this paper, we describe how to evaluate crane capacity decisions of a terminal regarding the impact on service quality and cost. For this purpose, we propose to generate service plans that take into account the projected crane capacity and the liner services calling at the terminal. Computational tests have shown how to exploit the quality of the service plans for deciding on the number of cranes to deploy. The presented computations base on randomly generated instance data. Therefore, validating the proposed technique on the basis of real-world data is an open task that will be addressed in future research projects. It is hoped to gain more insight into crane capacity decisions from investigating different terminals from practice. A further field of future research is constituted by the interdependencies between the quay space and the quay crane capacity of a terminal, which have been outlined briefly in our paper.

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Chapter 10
Planning Approach for Dimensioning of Automated Traffic Areas at Seaport Container Terminals

Michael Ranau

Abstract
In this article the quayside activities and layout of a modern container terminal are contemplated. The investigation particularly includes a comparison of two different automated operations systems regarding their space requirements: on the one hand, the AGV system which is in use at the Container Terminal Altenwerder in Hamburg and on the other hand, the automated SC system field tested at the Container Terminal on Fishermans Island in Brisbane. Both alternatives are used in combination with semi-automated cranes at quay wall and rail-mounted ASCs within the yard area. Main analysis objects are the quay wall with the container cranes as well as the traffic area between these cranes and the container yard. In addition, the operational functions of both systems and the dimensioning of their quayside traffic areas are illustrated.

10.1 Introduction

With the commissioning of the Delta/Sea-Land terminal in Rotterdam in 1993 the first robotized/automated Container Terminal started its operation (see ECT (2010)). In the year 2002 the Container Terminal in Hamburg Altenwerder followed this trend of automation (see CTA1 (2010)). In the subsequent years also other terminals have been starting with high degree of automation of operational processes. Due to the development of manpower costs it is expected that even in the high wage countries the number of automated terminals will increase in the future. Furthermore, the curtness of terminal-space in combination with automated high stacking density is another reason for terminal automation.

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In case of evaluation and planning of automated terminals one question arises very often. Why are the traffic areas between quay wall and the storage yard so large? On the first view these thoughts are understandable as on conventional terminals – like pure *S*traddle *C*arrier (SC) terminals – the traffic areas are much smaller. Due to this question the dimensioning of the quayside handling areas within an automated container terminal shall be evaluated in the following. As of the multiplied options of automation only two system variants for horizontal transport are compared and evaluated in detail, namely the *A*utomated *G*uided *V*ehicle (AGV) system and the automated SC system. Both variants are investigated in combination with *A*utomated *S*tacking *C*ranes (ASC) in the yard area operating container blocks arranged perpendicular to the quay wall. The ASC shall be rail-mounted (see, *e.g.* Kemme (Chapter 14 of this Handbook)) and the assumed block width comes to 10 containers.

The remainder of this paper is organized as follows. Section 10.2 provides a brief overview of the operational functions which occur on the quayside of a container terminal. In Section 10.3, the main planning assumptions for dimensioning of the quayside traffic area are described and layout results for two system variants of horizontal container transport are presented (AGV operation vs. automated SC operation). Lastly, Section 18.5 concludes the paper with a summary of main insights gained in the sections before and some remarks regarding instrumental support for layout planning of container terminals.

10.2 Operational Functions of Quayside Works

Before looking more closely on the automation, the different operational functions of a container terminal should be illustrated. As the main focus will be drawn on the quayside areas, just the quayside functions will be named in here. All the functions mentioned afterwards have to be fulfilled at the quay wall (discharging/loading of vessels) as well as in the area between quay cranes and container yard (horizontal container transport and handover). Some of these functions might be suitable for automation, some not. For this reason the integration of these functions within both areas should be evaluated in detail.

10.2.1 Twist-Lock Handling and Other Materials

Beside the standard operation with standard containers additional operational requirements arise on the quayside. Except for the boatmen after mooring of vessels the first operational things to be done is the handling of materials like twist lock cages etc. between vessel and quay. By way of example, the quay crane driver has to move the lashing people (by use of lashing cages) from the quay wall on board of the vessel and vice versa. Furthermore, the twist lock cages have to be placed on the crane lashing platform or within the quay crane portal (see Figure 10.2). Handling functions of this type are hardly to automate – what can be assumed for future as well. However, for standard coning and de-coning of twist locks several suppliers appeared with advanced technologies during the last years (see KALP (2010)).

10.2.2 Handling of Out Of Gauge Cargo

On almost every container terminal cargo must be handled which does not fit in a standard container due to the measures of commodities or oversize, respectively. This *O*ut *O*f *G*auge cargo (OOG) has to be handled manually on the quayside and is moved by means of special container types, like flat racks or platforms and open top containers. After unloading from a truck or another vessel the OOG has to be placed and stored in a dedicated non automated yard area.

OOG cargo handling and positioning within the OOG area is usually performed by reachstackers, the transport to/from the quay cranes by tractors and different kind of trailers. It is not expected that OOG can be handled in an automated way of transport now and in future.

10.2.3 Quayside/Vessel Access and Additional Services

On a container terminal variable persons for different purposes need access to the quay wall or just even the quayside. Vessel suppliers, linesmen, agents, police, customs, boatmen, ambulance, terminal personnel etc. have to get access to the quayside with vehicles of partly different size. Due to these functions a minimum space for access roads or ways has to be established on the quay wall. All these non automated functions and persons make a complete automation of the quayside activities impossible.

Additional services – like cargo securing or handling of damaged cargo – also have to be done by manual actions at quayside. Nowadays all these operational functions are not automatable and it may not to be expected that automation becomes possible in future.

10.2.4 Preparing of Break Bulk Cargo

Non-containerisable break bulk cargo, *e.g.* railway engines or cars, is placed and positioned under the quay crane with tractors and special trailers. As this kind of freight – also termed as project cargo – requires specific handling tools, procedures and care, a manual interference is needed. Special handling preparations of project cargo are usually fulfilled in the portal of quay cranes right before loading.

Furthermore, the handling of project cargo requires an over-height frame. Either this frame has to be moved manually from another place on the terminal or it will be stored on the quay crane. The figure below shows the over-height frame storing position at the HHLA Container Terminal Altenwerder. The frame is stored between the both landside quay crane legs.

Fig. 10.1 Storage position for over height frame at the HHLA Container Terminal Altenwerder

10.2.5 Transportation of Standard Containers to/from the Container Yard

The major amount of the arising cargo will be the standard container. Due to this high quantity of standardized cargo size, an automation of this cargo is reasonable. This relates in particular to the horizontal transport of containers between quay wall and the yard area, but also to parts of vertical transport activities being necessary at quayside for vessel loading/discharging and the storage of incoming/outgoing containers in the yard area.

10.3 Dimensioning of Quayside Traffic Area

In this section, planning assumptions for quayside layout of two different operations systems are described more closely considering alternatively AGV technology for horizontal container transport as in Hamburg Altenwerder and Rotterdam or automated SC similar to Fishermans Island in Brisbane, Australia (see Patrick (2010)). In both system variants the area between the quay wall and the automated stacking yard can be divided in 4 main functional terminal areas being partly or fully automated (see Section 10.3.2 to 10.3.4). Before planning assumptions and results for quayside layout are presented the potential of terminal automation is basically specified in respect of quayside operation.

10.3.1 Fields of Automation

As mentioned above not all functions on the terminal quayside can be automated. Due to this the areas from the quay wall towards the container storage are to be investigated in detail. Generally, there are following functional areas in which automation could be installed:

- partial automation at quay wall by quay cranes using double-trolley technology for container handling,
- full automation within the traffic area between quay cranes and container yard by means of automated transport units like AGV or automated SC,
- full automation within the storage area by implementing an automated yard crane system.

10.3.2 Quay Crane Portal

The operations procedures of quay cranes towards the vessel have to be done manually. It is not expected that these activities will be automated within the next years. On the other hand, container handling towards the terminal yard offers options for automation. As already mentioned the terminals in Rotterdam and Hamburg are working with automated horizontal handling equipment, namely the AGV, for a couple of years. In Hamburg, the necessary container handover between the manual operated (quayside) crane trolley and the AGVs is realized by a second fully automated trolley. Thus an interface between these two trolleys is required. For this purpose so called coning or lashing platforms are installed. By means of buffer positions for two 40 ft or 20 ft containers the transfer between manual and automated crane handling devices can be realized.

On the ground of quay crane portal a multitude of exercises have to be arranged and most of them – like OOG handling and project cargo – cannot be automated. Hence, an intelligent arrangement of automated and manual areas is necessary. Furthermore, the mode of operation of the quay crane is important. For instance, a tandem lift[1] crane with double trolley technology entails a different design as a semi-automated single or twin lift[2] quay crane. The coning platform requires at least space for checking and buffering four 20 ft (or two 40 ft) boxes in case of a

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[1] Tandem lift operation enables the simultaneous handling of two 40 ft or four 20 ft containers.

[2] Quay cranes with twin lift operations capabilities are able to shift either one 20 ft or one 40 ft container or simultaneously two 20 ft containers with a single crane move.

semi-automated tandem lift quay crane noticing that only four (two) positions may be critical from the point of view of time-efficient operation. In principle, tandem lift operation leads to growing space requirements and larger quay crane portals compared to semi-automated single or twin lift cranes.

Figure 10.2 shows a possible design of a semi-automated single or twin lift, double trolley quay crane enabling smooth container flow between vessel and horizontal transport equipment. The coning platform is located on the quayside of the crane portal and offers space for two 40 ft or 20 ft boxes. Beside handover operations between both crane trolleys, the container check and twist lock handling activities take place on the coning platform with a width of about 10m to 11m. Thus, twist lock boxes and the lashing cage for the lashing personal must be stored on the lashing platform as well.

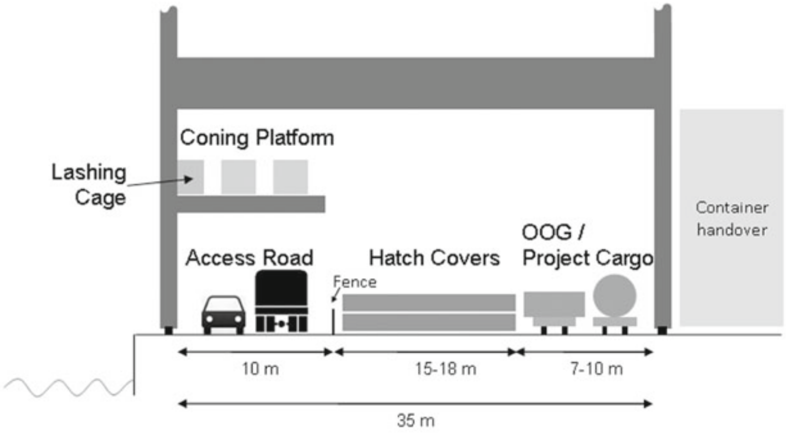

Fig. 10.2 Cross section of a quay crane portal

The most suitable position for the lashing cage is between the crane legs. Adjacent to the lashing cage the container lashing positions are situated. To guarantee the most suitable access for the lashing personal the twist lock boxes are located between the two container positions. Lashing material is usually moved by small forklift trucks in the quay crane portal. In case of an automated terminal this manual activities are fulfilled in the same area as the storing of hatch covers and the handling of OOG or project cargo. As the lashing material is usually handled by the quay crane itself, necessary pick up and drop down movements cannot be done under the lashing platform.

Underneath this platform the access road for berthing vessels is located. Vessel suppliers, terminal and maintenance personnel are using this road for access and parking purposes. Additional services like OOG or hatch cover handling are exe-

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Minimum space requirements of single or twin lift quay cranes for the lashing platform: One 40 ft or two 20 ft containers plus lashing materials.

cuted next to the access road separated by a fence within the quay crane portal. OOG and project cargo is normally positioned in the crane portal by tractors and trailers.

Most of the OOG and project cargo is stored on deck of a vessel. While handling under the quay crane it is expected that no hatch covers are under the crane at that time. Hence, approximately 25m should be sufficient for the handling of OOG or project cargo – enough space to use tractor trailer units or other equipment like heavy forklift trucks. The main preparation of OOG and project cargo is usually done in dedicated areas outside the crane portal. In respect of current operations conditions at container terminals and expected future development respectively, it is assumed that vessel hatch covers occupy between 15m to 18m of the crane portal. Consequently, a passage of 7m remains at the minimum for passing hatch cover positions with OOG or project cargo. Taking into account all these considerations the planning of crane portal width finally ends up about 35m in total.

Basically, the split up of automated and manual functions guarantees safe and efficient operation on the quayside. If the automated container handling shall take place within the quay crane portal, all manual procedures (including hatch cover stowage) would have to be fulfilled in the backreach, *i.e.* in an area surrounded by automated operations processes. The crossing of manual and automated handling activities would be mandatory and offset the benefits resulting from process automation.

Fig. 10.3 Quay crane portal at the HHLA Container Terminal Altenwerder

Furthermore, the automated container exchange between horizontal transport and quay cranes within the portal would lead to the necessity that transport units are to enter/leave this area by passing portals of all vessel operating cranes in the worst case (tunnel effect). All in all, the specific operations requirements of an automated handover area between the quay crane rails would lower the productivity of the horizontal transport units and thus increase the number of required units.

10.3.3 Quay Crane Backreach

The design of the crane backreach or the handover area respectively depends on the size and turning radius of horizontal transport units as well as on given peak requirements of vessel handling (*i.e.* the maximum number of quay cranes simultaneously used for loading/discharging per vessel). Basically, the width of each lane has to be dimensioned in such a way that the transport units must be able to enter driving lanes or waiting/holding positions without collision with any vehicle passing or parking in the nearest lane.

With a length of about 14.8m (width: approx. 3m) and an outer turning radius of 11.5m, AGVs require a driving lane width of around 4m. However, the driving lane towards the waiting/holding area needs a width of 5m. This additional 1m results from the running radius and from the projecting end appearing by the maximum steering angle. In comparison, automated SCs have a vehicle length of about 11.3m and a width of approx. 4.9m. Here, the vehicle length can be disregarded for lane design as the length dimension of some container types exceeds SC extent. The length of the largest loading unit (45 ft box: 13.72m) in combination with the outer turning radius of 10.1m of a loaded SC finally ends up with a driving lane width of around 6.4m.

As mentioned above, the number of lanes in the crane backreach depends also on peak handling requirements of the respective terminal. To serve a quay crane without waiting time the transport units must be able to get direct access to the handover position. Hence, in case of using four quay cranes per vessel call in maximum, four independent driving lanes are required. Two additional meters are needed to ensure clearance from crane machinery.

The backreach of quay cranes in case of the AGV system requires approximately 19m and around 28.6m are needed for operation of the automated SC variant. For both variants 2m of safety distance towards the quay crane were taken into consideration. As mentioned above, the system comparison was calculated with 4 lanes for each variant.

10.3.4 Waiting/Holding Area

Another relevant operations zone at quayside is the waiting/holding area for horizontal transport units. The waiting/holding area is projected for two different reasons. Firstly, it allows parking of transport units or containers respectively close to the dedicated quay crane, ensuring quay crane operation without any waiting time and thus a lack in productivity. Secondly, the non-operational transport units are to be placed somewhere. AGVs are partly parked in the handover areas of ASC blocks, since with certain probability an export or transshipment container will require an AGV in the near future anyway. Furthermore, non-operational automated SC cannot be parked in the handover area of ASC blocks as vehicles only get access to the area in case of a loading or discharging order for a dedicated container. Due to this reason all non-operational automated SC have to be parked in a waiting/holding area established for this purpose.

The width of a related area is to be laid out differently for both system variants. AGVs with an inner turning radius of 6.1m and an outer turning radius of 11.5m require a total width of the waiting/holding area of 28m (see Figures 10.4 and 10.5). It has to be mentioned that in particular the total length of the AGV is to be considered for area design as this measure primarily determines the outer vehicle turning radius. In respect of holding positions for automated SC the outer turning radius is defined by the dimension of longest loading unit (*i.e.* a 45 ft container) must be moved between quay cranes and ASC yard. With a length of 13.72m and width of 2.44m (4.94m width of automated SC) related boxes induce space requirements for the SC waiting/holding area that ends up with a maximum width of around 18.5m (see Figure 10.4).

In both variants additional space towards the landside and towards the waterside has to be considered. The handling devices require a minimum speed before starting the steering process. Basically, it has to be stated that the outer turning radius of transport units is of vital importance for the layout of their traffic areas and that decreasing values of this vehicle characteristic directly lead to increasing manoeuvring capabilities and finally to diminishing space requirements.

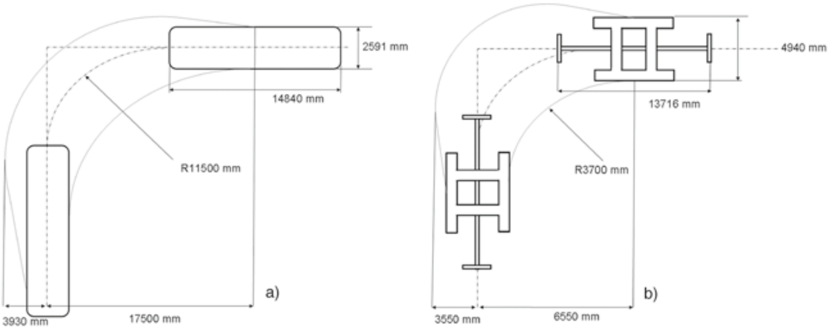

Fig. 10.4 Sample turning radius of a) an AGV (see Huege (2008)) and b) for an automated SC (see Noell (2010))

The waiting/holding area fulfills an additional operational task; namely the buffering of vehicles and containers. In respect of the operations systems considered by this paper horizontal transport connects two different logistics systems for container handling – the quay cranes at quay wall on the one hand and the ASC within the yard on the other hand. The use of transport units decouples both systems basically differing in their operations mode and logistic performance capabilities. Thus, idle times and clogging due to disharmonious (direct) system interaction can be reduced or ideally avoided (see, *e.g.* Markwardt (2004)). In this context, the implementation of waiting/holding positions for horizontal transport units additionally increases the degree of system decoupling since possibilities for container and vehicle buffering are basically extended. Due to less operational flexibility of automated system components decoupling gets momentous importance in case of automation.

Fig. 10.5 AGVs in the waiting/holding area at the HHLA Container Terminal Altenwerder

10.3.5 Main Driveways

Next to the waiting/holding area towards the terminal yard the main driveways are located. Subject to the quay length and the expected transport volume, the number of driveways has to be implemented. In Hamburg-Altenwerder six main driveways with a quay length of about 1,400m are established (see CTA2 (2010)). These driveways shall ensure a smooth operating without any congestion or waiting of transport units between the ASC blocks and the waiting/holding area. Hence, a waiting position close to the handover lane of the ASC block assigned for container exchange is of prime importance as well. The width of an AGV lane has to be considered with 4m and 5m for inner lanes towards the waiting/holding positions. In respect of the elaborated sample layout five driveways are considered within the AGV traffic area. The width of the automated SC lane is about 6.4m or 7.4m, respectively (see Section 10.3.3). For the AGV system a distance of 8m between the (outer) main driveway and the quayside end of ASC rails are taken into consideration. However the SC variant requires in the same area 5m. This distance are required to guarantee a safe ‘run-in’ and ‘-out’. Thus, the AGV system finally ends up with a driveway proportion of 29m. However, the automated SC variant needs in case of five main driveways 38m.

Fig. 10.6 Main driveways in front of ASC blocks at the HHLA Container Terminal Altenwerder

As already mentioned, it is obvious that the width and length of the (loaded) transport units or their outer turning radius and the determines the dimensioning of the traffic area between quay cranes and container yard decisively. Depending on the part to be configured the length and width dimension of transport units differ in their influence on the layout. For instance, the scale of vehicle width is of less interest for dimensioning of the waiting/holding area (see Section 10.3.4) but becomes more important for the crane backreach and main driveways if four or five parallel vehicle lanes are to be considered (see Section 10.3.3). All in all, the use of almost 5m wide automated SC and an around 3m wide AGV results in a substantial difference regarding the total width and partitioning of the quayside traffic area.

10.3.6 Planning Results

Based on the planning assumptions described in the preceding sections the design of the entire traffic area is subsequently presented for both horizontal transport systems. Figure 10.7 shows the sample of the AGV layout that ends up with space requirements of about 76m with regard to the distance between landside quay crane rail and the quayside end of ASC rails. The main basis for this calculation forms the assumption of the AGV width (approx. 3m) and the outer AGV turning cycle (approx. 11.5m).

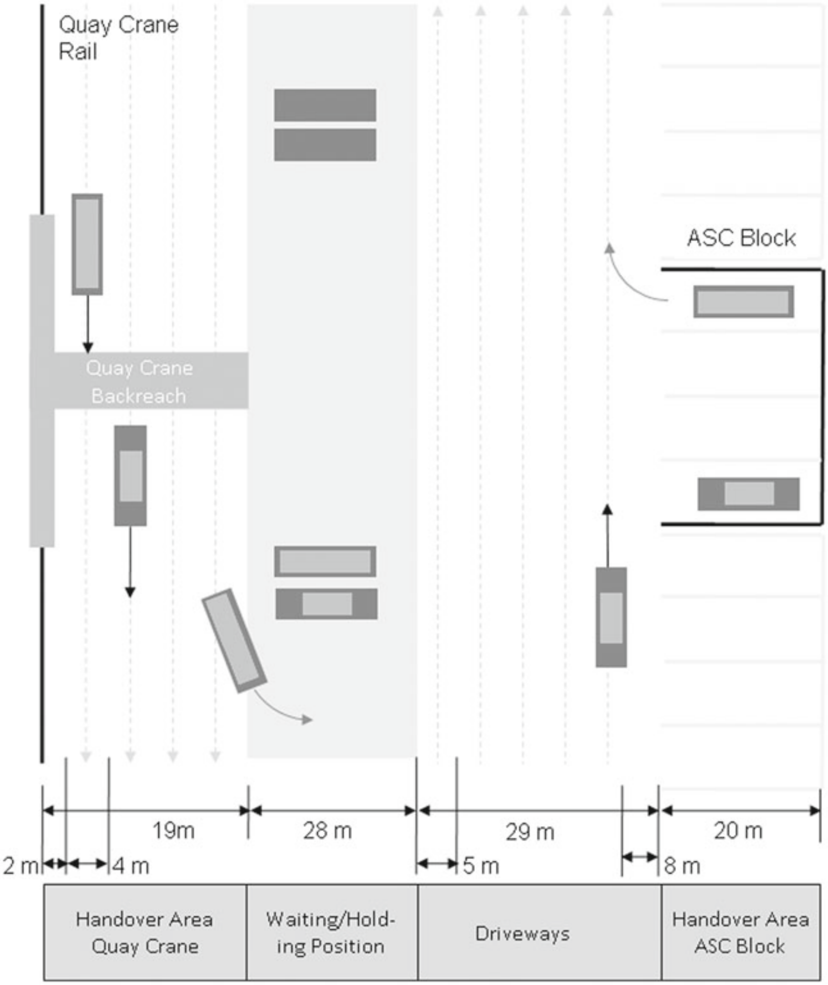

Fig. 10.7 Top view on the AGV layout (stylized illustration)

The automated SC system investigated as second transport variant results in a different total area width. The distance between quay cranes and and the quayside end of ASC rails amounts to around 85 meters. In spite of the smaller outer turning radius and thus smaller waiting/holding area the SC variant requires a larger traffic area taking account of given planning assumptions. This is mainly induced by wider transport units leading to increased space requirements for driving lanes. The automated SC comes to a width of almost 5m that considerably exceeds AGV width with about two additional meters.

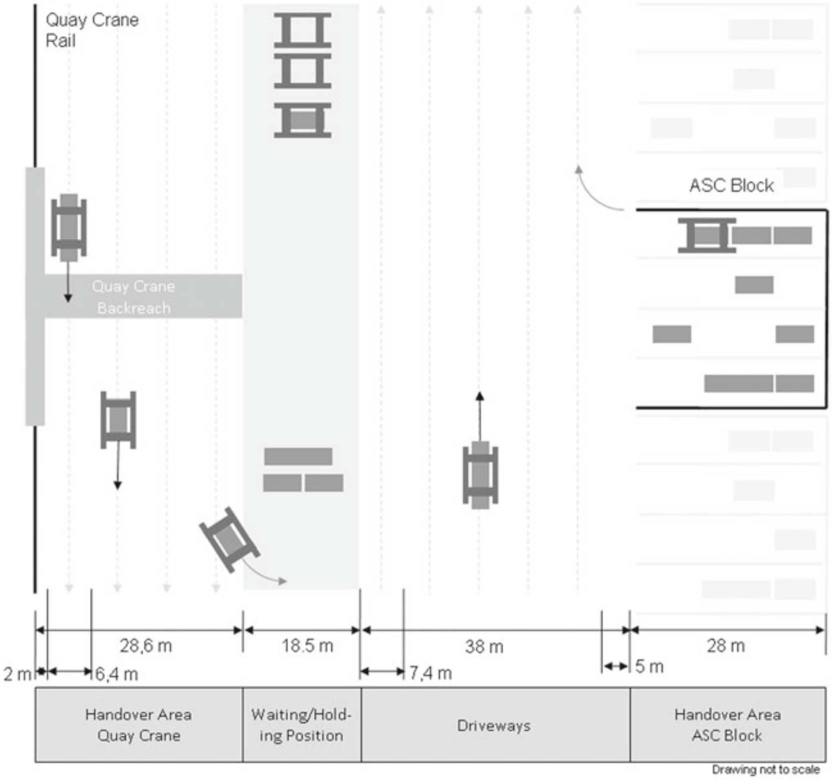

Fig. 10.8 Top view on an automated SC layout (stylized illustration)

10.4 Conclusion

For the automation of container terminals on the quayside various possibilities do exist. In the foregoing sections just two automated operations systems were discussed more detailed, namely the AGV and the automated SC variant, both in combination with semi-automated quay cranes at quay wall and rail-mounted ASC within the yard area.

For a comparison of transport systems regarding their space requirements similar planning assumptions are taken into account, *e.g.* container handover is to be done in the backreach of quay cranes using four driving lanes to approach/leave handover positions. Usually, layout assumptions depend on a multitude of (local) parameters, inter alia the length of the quay wall, the number of quay cranes, the percentage of transshipment, etc. To support related design decisions or validate assumptions made for layout dimensioning respectively, simulation of logistic terminal processes represent an effective instrument (see Stahlbock and Voß (2008) and Wiese et al (Chapter 12 of this Handbook)). For instance, the definition and execution of appropriate simulation experiments help to determine the right number of main vehicle driveways allowed for layout requirements of the respective application case.

The result of the system comparison shall not be the statement on a better or worse variant. On the contrary, the investigations purpose is to present a general approach for layout planning of automated operations systems and to reveal basic layout requirements arising out of the use of AGVs or automated SCs on the terminal quayside.

Additionally, the mandatory decoupling of different logistic systems interacting with each other at container terminals is an issue of the paper. On this matter, the particular role of horizontal transport equipment and the design of its traffic area are emphasized for smooth and time efficient container handling. In case of transport automation, one point is lost of sight very often, namely the necessity of parking areas for leaving automated transport units (*e.g.* AGV) enduringly. The non-operational equipment pieces have to be placed within related traffic areas to avoid constrictions of quayside container flow.

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Chapter 11

Cost and Performance Evaluation Impacts of Container Vessels on Seaport Container Terminals

Günther Pawellek and Axel Schönknecht

Abstract
The subject of this paper is a method of evaluating cost and performance of container ships as means of transport in the main part of the intermodal transport chain for ISO containers. The reason for doing so is the continuous development in the size of container ships and the infrastructure development to cater for them, as well as the transport chain development in pre- and on-carriage that cannot be evaluated as riskless. The method described will make clear that the factors for success or lack of success for large container ships can be found almost exclusively in the ports and their hinterland infrastructure.

11.1 Introduction

Due to the continuously increasing transport volume in sea container traffic, the call for bigger and bigger container ships is increasing from many sides. The latest generations of container ships have already been ordered at a cost of up to 27 billion US $ (according to Drewry (2008)). With ever bigger ships considerably more containers could be shipped per container ship round trip than today, the turnover will increase and with it the profits, according to the theory of *e.g.* Ihlwan (2003). This theory will only be proven if costs develop sub-proportionally to the size of the vessel, and the number of container ship round trips remain almost the same. The combination of the criteria 'income', 'cost' and 'container ship round trips' in a

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Operations Research/Computer Science Interfaces Series 49,
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particular time period, in short the tonnage or slot productivity, is hardly ever considered in the discussion on the development of the size of the ships. This depends on many logistics influencing factors. If slot productivity does not increase as the ships become bigger, or even reduces, then the giant container ships ultimately achieve a lower return on investment. If this happens, according to Stopford (2002), then a similar development as with the giant tankers in the 1970s is to be feared, which were scrapped almost overnight. Infrastructure created up to that time, mostly with public funding, proved to be useless. The development in the size of container ships up to today is illustrated in Figure 11.1.

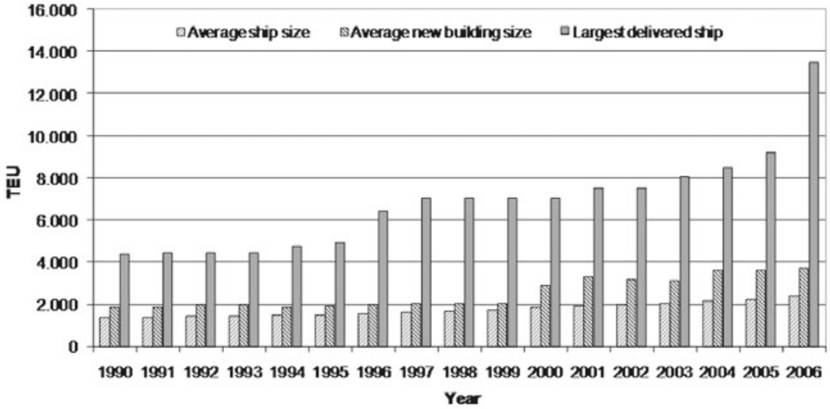

Fig. 11.1 Development of the average and maximum container ship size; based on Drewry (2008)

In order to check the sustainability of container ship growth, a method is required that shows container ships' typical operating performance. This method is the main content of the following article and should show which primary factors influence container ship profitability and productivity and what repercussions the continual growth in ship size could have on the transport chain and its interfaces, or what alignment measures need to be taken in the ports to achieve maximum profitability for the large container ships. Initially the correlation between the transport chain and a container ship loop should be explained briefly in Section 11.2.

11.2 Placement of Container Ships on the Transport Chain

An intermodal transport chain is defined as the transportation of goods in the same transport box using at least two different means of transport. The transport chain illustrated here is divided into pre-, main, and on-carriage. The use of at least three means of transport is necessary per transport chain, with a container ship deployed as the main means of transport. A diagram is necessary to show the importance of the container ship in the transport chain and the connection between the transport chain as a part of the transport procedure for one and the same unit of cargo, as well as the deployment of a container ship for many different cargo units in the framework of many different transport chains (see Figure 11.2).

The operational deployment form for container ships in liner shipping trade is primarily the round trip or loop. Round trip is here a shipping term that has nothing to do with round trips in operations research. Included in the round trip defined here, the same port can be called at many times. But the starting port and the final port are identical. The basics of round trips in liner shipping are very well explained in Breitzmann and Schönknecht (2006). Round trips in liner shipping are usually between two continents. Asia – North America, Asia – Europe and Europe – America are the most important trades.

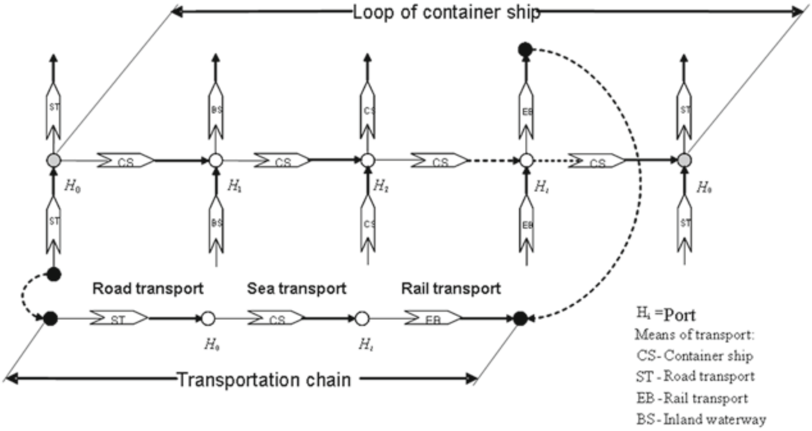

Fig. 11.2 Correlation between transport chain and a container ship round trip

It is the job of every port to concentrate cargo from different transport chains for loading into a container ship or to distribute these goods across the transport chains. Figure 11.3 illustrates the influence of the size of the container ship on the task and the number of transport chains to be connected.

Accordingly, the number of transport chains and containers to be handled, which are concentrated on one ship's departure or to be distributed from the ship depend on the net loading capacity of the ship N_{CS}[1] as well as a factor Δ. Factor Δ represents how many containers are to be handled in proportion to the ship's loading capacity. This can vary between imports and exports.

The net loading capacity N_{CS} of container ships grows constantly. This is well known. It is unknown is whether it is a temporary occurrence, similar to the giant tankers of the 1970s already mentioned, or whether very large container ships are

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[1] The net loading capacity of a ship in usually smaller than the net slot capacity of a ship. A weight of 14 tons must be taken into consideration per slot (see Cullinane and Khanna (1998)). Therefore the deadweight capacity of a ship is reached before all slots are filled.

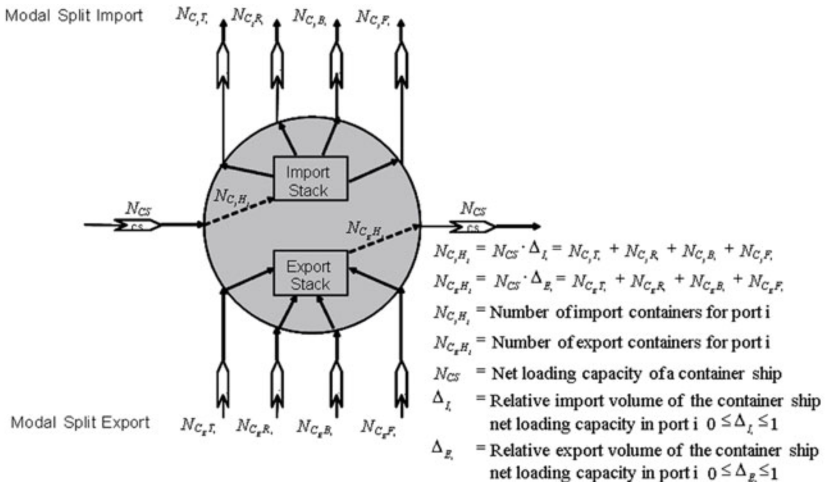

Fig. 11.3 Influence of the size of a container ship on the number of transport chains to be served in port *i*

to be expected in ports over a long period of time. Furthermore, there is a need for further research to see how the factor *Δ* develops depending on container ship size and whether it affects or makes demands on the modal split of means of transport in pre- and on-carriage in the ports. To answer these questions, a case can be made that the dimensions of container ships can develop over a long period of time, so that maximum efficiency can be achieved. In order to estimate the cost efficiency of various sizes of container ships, a model of the cost and revenue parameters of a container ship's round trip is necessary and is introduced below.

11.3 Cost and Revenue Model of a Container Ship in Liner Shipping

It is a prerequisite that a model is sought here that can compare the profitability of various sizes of container ships and not reflect the exact profitability of a single round trip. Ships taken into consideration in this survey have been chosen in the following size clusters (see Table 11.1).

11.3.1 Cost Model

Subsequent explanations focus on the cost model for the calculation of vessel operations expenses on pre-defined round trips assuming a particular vessel size or class, respectively. In Subsection 11.3.1.1 a model approach is developed for the

Table 11.1 Definition of the ship-size clusters to be surveyed

Cluster	Deadweight Capacity [dwt]	Container Capacity [TEU]	Net Container Capacity [TEU]	Reference Capacity [TEU]	Speed [kn]	Engine Power [kW]	Length [m]	Registered Tonnage
TEU 0-1,000	7,673	645	548	548	17	5,833	116	6,452
TEU 1,000-2,000	22,575	1,400	1,613	1,400	19	10,763	169	17,315
TEU 2,000-3,000	40,336	2,761	2,881	2,761	21	22,760	225	34,649
TEU 3,000-4,000	46,510	3,595	3,322	3,322	24	31,670	251	39,698
TEU 4,000-5,000	66,327	4,848	4,738	4,738	23	36,877	288	57,898
TEU 5,000-6,000	76,622	6,289	5,473	5,473	25	64,713	292	70,552
TEU 6,000-7,000	87,943	6,744	6,282	6,282	25	60,173	306	80,420
TEU 7,000-8,000	101,429	7,523	7,245	7,245	25	63,990	330	89,717
TEU 8,000-9,000	104,203	8,546	7,443	7,443	25	68,387	334	92,583
TEU 9,000-10,000	108,956	9,216	7,783	7,783	25	70,346	346	103,498
TEU 10,000-11,000	152,000	12,670	10,857	10,857	23	70,000	390	150,000
TEU 11,000-12,000	157,000	11,989	11,214	11,214	25	91,537	400	142,418
TEU 13,000	175,000	13,640	12,500	12,500	23	77,941	400	150,000
TEU 18,000	242,800	18,154	17,343	17,343	25	116,588	400	239,380

cost-related representation of vessel round trips using parameters of k specific ports. Afterwards, the approach is generalized in Section 11.3.1.2 leading to a cost model that includes the same port parameter characteristics for all (or a certain group of) round trip destinations (*e.g.* regarding handling volumes or quay tariffs). Generalization simplifies model application and extends options for exploration without affecting the quality of analysis results in respect of investigation objectives discussed in Section 11.1.

11.3.1.1 Round Trip Cost Model

The approach for the cost model will initially be made from a round trip out of k ports, where the ports H_0 and H_k are identical and between each port a distance s_i is to be covered (see Figure 11.4).

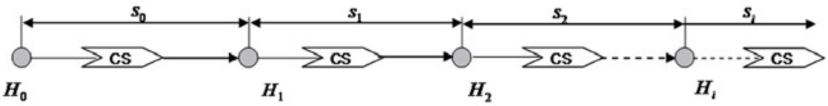

Fig. 11.4 Illustration of a round trip in container liner shipping

The sum of all part distances s_i is the same length as the round trip s_R. In each port H_i the number of containers for export N_{C_E} as shown in the diagram of Figure 11.5 for loading and the number of containers imported N_{C_I} for discharge; the containers can be 20 ft or 40 ft.

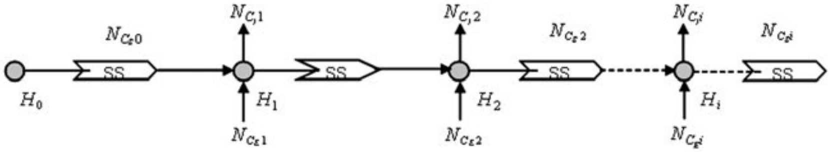

Fig. 11.5 Number of containers handled in a round trip

The number of containers moved between ports $N_{C_s i}$ cannot be bigger than the loading capacity of a ship N_{CS} multiplied by a utilization factor α. To sum up for the number of containers per port:

$$\begin{aligned}
N_{C_s}i &= N_{C_s}i-1 - N_{C_I}i + N_{C_E}i \\
N_{C_I}i &= N_{C_{I_{20}}}i + N_{C_{I_{40}}}i \\
N_{C_E}i &= N_{C_{E_{20}}}i + N_{C_{E_{40}}}i \\
N_{C_s}i &\leq N_{CS} \cdot \alpha \\
0 \leq \alpha &\leq 1
\end{aligned}$$

The net loading capacity N_{CS} of a ship in containers depends on the split of 20 ft and 40 ft containers. This split is expressed as the TEU factor F_{TEU}. The relation between container quantity and container volume N_{TEU} is as follows:

$$\begin{aligned}
F_{TEU} &= \frac{N_{TEU}}{N_C}; 1 \leq F_{TEU} \leq 2 \\
N_{TEU} &= N_{C_{20}} + 2 \cdot N_{C_{40}} \\
F_{TEU} &= \frac{N_{C_{20}} + 2 \cdot N_{C_{40}}}{N_c} = 1 + \frac{N_{C_{40}}}{N_C} \\
N_{C_{40}} &= N_C \times (F_{TEU} - 1) \\
N_{C_{20}} &= N_C - N_{40}
\end{aligned}$$

And so the ship's net loading capacity can be expressed as:

$$N_{CS} \leq \frac{NTEU_S}{F_{TEU_S}}$$

where $NTEU_S$ is the ship's capacity in net TEU.

Within this framework a container ship round trip time T_R can be calculated as the sum of sea-time T_{s_i} and port lay time T_{L_i}(see Figure 11.6).

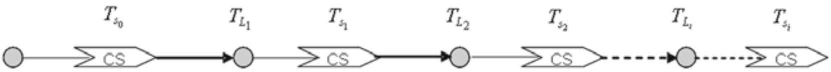

Fig. 11.6 Time components of a round trip

The time at sea per part trip s_i is simplified here and calculated as follows:

$$T_{s_i} = \frac{s_i}{V_s}$$

Port lay time is made up of a consistent arrival and clearance time T_{H_i} as well as handling time, depending on the number of containers in total T_{U_i}.

When calculating handling time the specific handling time, T_{UM} for a loading or unloading action per container quay crane, as well as the number of quay cranes N_{CB}, it is possible to deploy on one container ship are of importance. This can vary from port to port and can also be a function of the ship size. The influence of poor stowage planning should not be taken into consideration. Up to now, only single moves occur in container loading worldwide.

A container ship's lay-time in port can be expressed as:

$$T_{L_i} = T_{H_i} + (N_{C_I i} + N_{C_E i}) \cdot \frac{T_{UM_{H_i}}}{N_{CB_{H_i}}}$$

With time and specific volume of a round trip the various costs can be calculated and the total cost K_R added up. Within this scope there are five cost types, which occur during a round trip, or which costs must be distributed.

$$K_R = K_{FR} + K_{VSR} + K_{VHR} + K_{UR} + K_{sonst}$$

with:

K_{FR} = Fixed costs
K_{VSR} = Variable costs at sea (*e.g.* bunker costs)
K_{VHR} = Variable port costs (*e.g.* port and pilto dues)
K_{UR} = Variable handling costs
K_{sonst} = Additional costs *e.g.* Suez Canal

The fixed costs per round trip are made up from a specific cost factor depending on the size of the ship K_{FS} [EUR/time] and the time taken for the round trip T_R in total:

$$K_{FR} = K_{FS} \cdot T_R$$

Variable costs at sea

$$K_{VS_{s_i}} = K_{VS} \cdot T_{s_i}$$

$$K_{VSR} = \sum_{1}^{k} K_{VS_{s_i}}$$

and variable port costs are similarly calculated

$$K_{VH_i} = K_{HS} \cdot T_{L_i}$$

$$K_{VHR} = \sum_{1}^{k} K_{VH_i}$$

The specific cost factors K_{FS}, K_{VS} and K_{HS} per ship size are given using an extra calculation method. For specific fixed costs K_{FS} large scale or economy of scale effect is proven (see Figure 11.7), but not for all other specific cost factors. Furthermore it is to be noted that port costs K_{HS} are usually for each 24-hour period started.

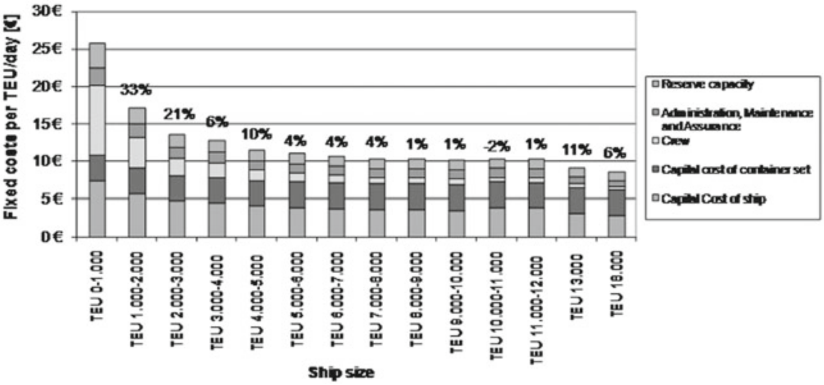

Fig. 11.7 Distribution of fixed costs depending on the size of the ship and relative change to its predecessor on the top of the columns[2] (see Schönknecht (2009), p. 46)

Handling costs for each container are due in relation to the quay tariff $K_{KAI_{20_{H_i}}}$ and $K_{KAI_{40_{H_i}}}$. Handling costs for a round trip can be expressed as:

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[2] Calculation based on the NTEU capacity.

$$K_{U_i} = K_{U_{20_i}} + K_{U_{40_i}}$$

$$K_{U_{20_i}} = \left(N_{C_{I_{20}}i} + N_{C_{E_{20}}i}\right) \cdot K_{KAI_{20_{H_i}}}$$

$$K_{U_{40_i}} = \left(N_{C_{I_{40}}i} + N_{C_{E_{40}}i}\right) \cdot K_{KAI_{40_{H_i}}}$$

$$K_{UR} = \sum_{1}^{k} K_{U_i}$$

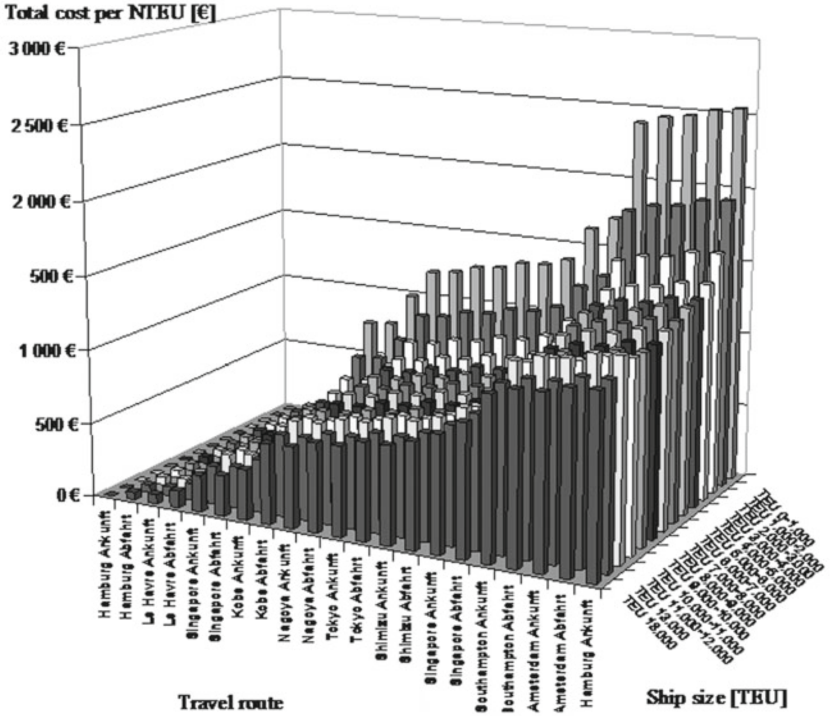

Fig. 11.8 Example of cost development of a round trip per slot for various container ship sizes in the ship-size clusters in 2008[3]

On the basis of a particular round trip, the costs for various types of ships can now be calculated per round trip and compared. As an example the results of a Europe – Asia round trip are illustrated in Figure 11.8. The model used to date is also suitable

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[3] Fixed costs from Figure 11.7, ship data according Table 11.1, assumption of engine utilization for service speed 90%, specific fuel consumption 171 g/kWh, bunker price 250EUR/t, container handling speed according to empiric data per TEU of Port of Hamburg, handling volumes 25%–50% of ship net loading capacity in each port, handling charges 95 EUR per TEU in Europe and 80 EUR per TEU in Asia, port dues according to the average of Port of Hamburg and Rotterdam.

as a basis for a round trip simulation, in particular to show how events in port that are difficult to define (*e.g.* various handling procedures) can affect a round trip. The varying parameters, *e.g.* handling volume, quay tariffs etc. in this model must be applied in a particular port. This is not always possible or it is open to discussion whether under particular conditions for one port the results would be very different. As it is impossible to simulate all variations of a round trip that exist between several continents for all ship sizes, the cost model must be abstract enough so that no concrete round trip is necessary as a basis for cost calculation.

11.3.1.2 General Cost Model

The number of containers N_{CR} handled in a round trip like in Figure 11.9 can be determined for each ship as:

$$N_{CR} = \sum_{1}^{k} (N_{C_I}i + N_{C_E}i)$$

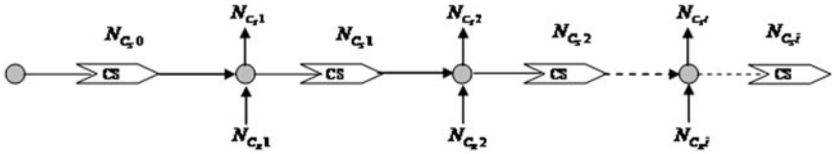

Fig. 11.9 Determining full container volumes

Given that, per port:

$$N_{C_I}i + N_{C_E}i = \Delta_i \cdot \frac{NTEU_s}{F_{TEU_s}} \cdot \alpha$$

where Δ_i the amount of containers in port i is measured in proportion to the ship's total capacity. Using α the already mentioned possible reduced utilization due to a reduced amount of cargo is taken into account. Therefore, the number of containers handled is:

$$N_{CR} = \sum_{1}^{k} \Delta_i \cdot \frac{NTEU_s}{F_{TEU_s}} \cdot \alpha = \frac{NTEU_s}{F_{TEU_s}} \cdot \alpha \cdot \sum_{1}^{k} \Delta_i$$

The total proportion of handling per port and slot can be defined as re-use W_R of a slot per round trip.

$$\sum_{1}^{k} \Delta_i = 2 \cdot W_R$$

One re-use per slot means that in the course of a round trip one container will be discharged and another loaded. If a ship within the scope of a round trip sails *e.g.* only between two ports, re-use can happen twice max. Four handling procedures would be necessary for this.

Therefore, the number of containers handled per round trip N_{CR} and the handling operations necessary to achieve this, through the ship's net loading capacity in TEU, a utilization factor and an assumed slot re-use can be determined.

$$N_{CR} = \frac{NTEU_s}{F_{TEU}} \cdot \alpha \cdot 2 \cdot W_R$$

Each move will be charged at a quay tariff. These rates are different for 20 ft and 40 ft containers and between different continents. The breakdown of moves N_{CR} for 20 ft and 40 ft is expressed as follows:

$$\begin{aligned} N_{CR} &= N_{C20R} + N_{C40R} \\ N_{C20R} &= \left(\frac{2NTEU_s}{F_{TEU}} - NTEU_s \right) \cdot \alpha \cdot 2 \cdot W_R \\ N_{C40R} &= \left(NTEU_s - \frac{NTEU_s}{F_{TEU}} \right) \cdot \alpha \cdot 2 \cdot W_R \end{aligned}$$

In terms of distribution of handling operations between continents, one can assume that half of the movements in a round trip occur on one continent. To simplify things, the same quay tariffs are assumed for one continent. The different quay tariffs can be expressed using a factor β, *e.g.*:

$$K_{KAI_{20_{Asien}}} = \beta \cdot K_{KAI_{20_{Europa}}}$$

Based on these assumptions, the time components[4] of a round trip of k ports can be calculated as follows, without knowing them exactly:

$$\begin{aligned} T_R &= T_{s_R} + T_{L_R} \\ T_R &= \frac{s_R}{V_S} + k \cdot T_H + \frac{NTEU_S}{F_{TEU_S}} \cdot 2 \cdot \alpha \cdot W_R \cdot \frac{T_{UM}}{N_{CB}} \end{aligned}$$

Building on this, the cost components can be generated:

$$\begin{aligned} K_{FR} &= K_{FS} \cdot \left(\frac{S_R}{V_S} + n \cdot T_H + \frac{NTEU_s}{F_{TEU_S}} \cdot 2 \cdot \alpha \cdot W_R \cdot \frac{T_{UM}}{N_{CB}} \right) \\ K_{VSR} &= K_{VS} \cdot \frac{S_R}{V_S} \\ K_{VHR} &= K_{HS} \cdot k \\ K_{UR} &= \alpha \cdot W_R \cdot (1+\beta) \cdot \\ & \left(K_{KAI_{20_{Europa}}} \left(\frac{2NTEU_S}{F_{TEU_S}} - NTEU_s \right) + K_{KAI_{40_{Europa}}} \left(NTEU_s - \frac{NTEU_s}{F_{TEU_S}} \right) \right) \end{aligned}$$

Other costs remain unchanged in this calculation.

11.3.2 Earnings Model

The explanations of the following subsections refer to the earnings model for calculation of vessel operations revenues on pre-defined round trips assuming a particular vessel size or class, respectively. Subsection 11.3.2.1 describes the revenue components which may be considered for this purpose. Analogously to the cost modeling approach, a generalized model for vessel operations revenues is developed in Section 11.3.2.2. The model includes the same port parameter characteristics for all (or a certain group of) round trip destinations (*e.g.* regarding freight rates or terminal handling charges) making the procurement of specific port information unnecessary.

11.3.2.1 Earnings Model for a Round Trip

Every container transported creates costs. But only full containers can generate earnings. When calculating earnings, worldwide imbalances Q_R are to be taken into con-

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[4] Handling times based on empiric data of average berthing time per TEU of Port of Hamburg (see Schönknecht (2009), p. 55)

sideration. Imbalances are differences in goods flows between continents. In 2007 these imbalances in full container flows are shown in Figure 11.10.

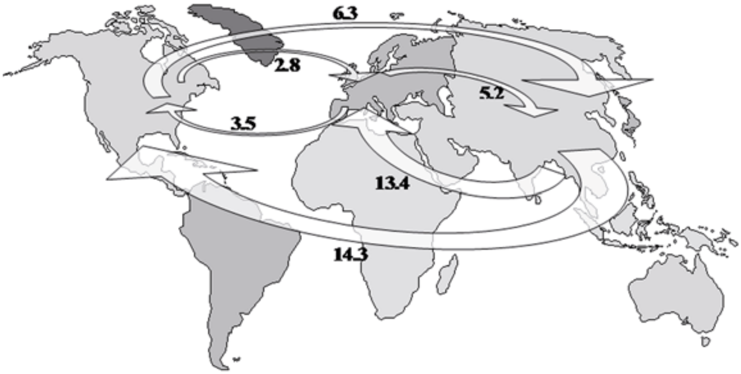

Fig. 11.10 Distribution of full container flows in million TEU in 2007 between Europe, Asia and North America; based on Drewry (2008)

In trans-pacific trades the imbalances in 2007 were at least approximately 56%. These imbalances not only caused differences in the flow of full containers but also varying freight rates according to direction. In the fully utilized direction, a considerably higher freight rate can be achieved than in the other direction.

Imbalances must be taken into consideration when ascertaining the volume of full containers for a round trip N_{CVR} and also the appropriate freight rates. The volume of full container traffic for a round trip is made up of the sum of full containers for export $N_{C_{EV}}$ per port (Figure11.11).

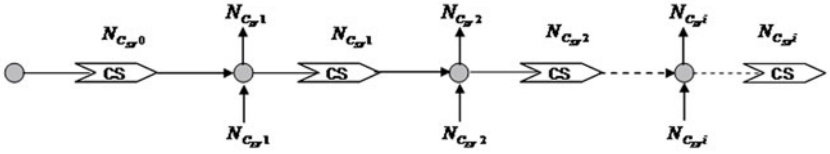

Fig. 11.11 Full container volume for a round trip

$$\begin{aligned}
N_{C_{SV}i} &= N_{C_{SV}i-1} - N_{C_{IV}i} + N_{C_{EV}i}\\
N_{C_{SV}i} &\leq NTEU_S \cdot \alpha \cdot (100\% - Q_{R_i})\\
0 \leq \alpha &\leq 1; 0 \leq Q_{R_i} \leq 100\%\\
N_{CVR} &= \sum_1^k N_{C_{EV}i}
\end{aligned}$$

When considering earnings, the difference between 20 ft and 40 ft-containers is to be taken into consideration:

$$\begin{aligned}
E20_{H_i} &= N_{C_{EV_{20}}i} \cdot E_{C_{20}}\\
E40_{H_i} &= N_{C_{EV_{40}}i} \cdot E_{C_{40}}\\
E_{H_i} &= E20_{H_i} + E40_{H_i}\\
E_R &= \sum_1^k E_{H_i}
\end{aligned}$$

Earnings per container E_C are made up not only of freight rates but also of the bunker adjustment factor BAF_{TEU}[5], the currency adjustment factor CAF_{TEU}, as well as terminal handling charges THC, which are different for 20 ft and 40 ft containers and for dispatch and receiving ports.

As it is very difficult to allocate possible earnings to specific ports, the model is adjusted so that earnings can be calculated not based on any particular round trip.

11.3.2.2 General Earnings Model

In order to simplify things, it will also be assumed here that earnings per container which are attainable on one continent can be expressed in relation to attainable earnings on another continent

$$E_{C_{Asia-Europe}} = \delta \cdot E_{C_{Europe-Asia}}$$

The amount of full containers is the same as half the amount of handling movements in the round trip, when the imbalance is 0%. In an area with an imbalance, full container volume is reduced by the difference of imbalance volume and full capacity.

$$N_{CVR} = \frac{NTEU_S}{F_{TEU}} \cdot \frac{\alpha}{2} \cdot W_R + \frac{NTEU_S}{F_{TEU}} \cdot \frac{\alpha}{2} \cdot W_R \cdot (100\% - Q_R)$$

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[5] Container shipping lines collect an additional and variable extra charge in the form of this factor, so as to compensate bunker price up- and down-turns.

When calculating earnings, the differing freight rates[6] for 20 ft and 40 ft containers are to be applied. In areas of imbalance, freight rates are reduced by the factor δ. Earnings from full 20 ft containers per round trip can be calculated as:

$$E20_R = E_{C20_{Europe-Asia}} \cdot \left(\frac{2 \cdot NTEU_S}{F_{TEU}} - NTEU_S \right) \cdot \frac{\alpha \cdot W_R}{2} \cdot (1 + \delta \cdot (100\% - Q_R))$$

Earnings for 40 ft containers can be calculated using:

$$E40_R = E_{C40_{Europe-Asia}} \cdot \left(NTEU_S - \frac{NTEU_S}{F_{TEU}} \right) \cdot \frac{\alpha \cdot W_R}{2} \cdot (1 + \delta \cdot (100\% - Q_R))$$

The sum of earnings of the two container types show total earnings per round trip.

11.3.3 Evaluating Return and Performance

Based on model approaches developed in the section before, overall cost and revenues of common vessel classes are calculated for a round trip of 10 (arbitrary) ports on the Asia-Europe route assuming various slot re-use rates. Cost and revenue figures resulting from model application are aggregated to meaningful economic indicators of vessel operation. For each vessel class, the return on investment (Subsection 11.3.3.1) and the vessel performance (Subsection 11.3.3.2) are investigated and appropriately illustrated, considering sensible variations in the slot re-use rate.

11.3.3.1 Evaluating Return on Investment (ROI)

The ROI on a round trip is a simple measure of the profitability of a round trip (see Müller and Schönknecht (2005)). It is defined as the relationship between profit and cost.

$$R_R = \frac{E_R - K_R}{K_R}$$

The ship cluster defined in Table 11.1 and typical parameters of an Asia-Europe round trip shows the profitability of Figure 11.12.

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[6] Freight rates include all elements, *e.g.* BAF, CAF and THC.

[7] Fixed costs from Figure 11.7, ship data according Table 11.1, assumption of engine utilization for service speed 90%, specific fuel consumption 171 g/kWh, bunker price 212 EUR/t , container handling speed according to empiric data per TEU of Port of Hamburg, handling volumes 200%–300% of ship net loading capacity over all ports, average handling charge 108 EUR per TEU, port dues according to the average of Port of Hamburg and Rotterdam in each port, freight rate A-E 20 ft 1,410 $, freight rate A-E 40 ft 2490 $, freight rate E-A 20 ft 550 $, freight rate A-E 40 ft 900

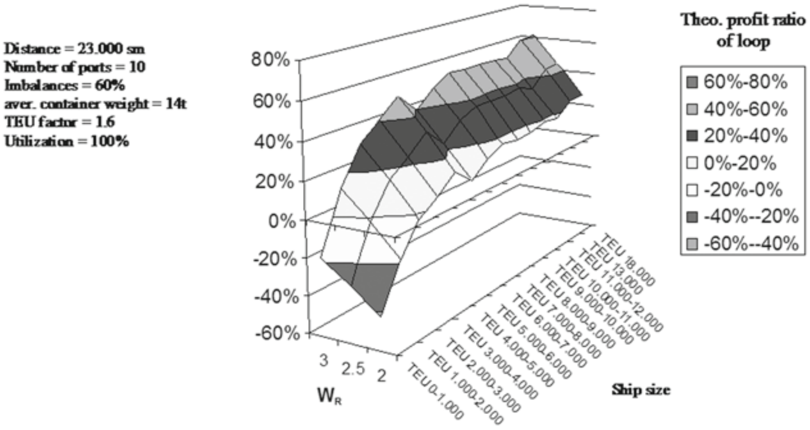

Fig. 11.12 Profitability comparisons between various ship types in 2008[7]

Today smaller vessels up to approximately 2,000 TEU are apparently no longer in a position to carry out profitable voyages on the Asia-Europe route. Not until they are about 3,000 to 4,000 TEU can they make a noteworthy profit. Above a size of about 8,000 TEU profitability stagnates and only in the region above 13,000 TEU does it rise again slightly. At present, there are only some vessels with a gross slot space of 13,000 TEU. Whether the ships in Table 11.1 reach the given speeds is questionable, as contrary to previous assumptions, ships like these only have one screw. Every reduction in speed leads on the one hand to a decrease of bunker cost but on the other hand to an increase in the length of a round trip and more fixed costs come into the profitability calculation. The 18,000 TEU vessel, published by Wijnolst et al (2000), is still in the planning phase, and is therefore not taken into consideration.

The longest time increase in a round trip can happen in the ports. When looking at time in port and at sea for a round trip, it becomes clear that the time difference between about 3,000 to 4,000 TEU almost always occurs in port (see Figure 11.13). As regards port lay time it should be noted that a considerable calculation process, or rather the parameters to be used with buffer time and the number of container quay cranes per ship are completely theoretical, being concerned with planning of new terminals. Actual measurements in the Port of Hamburg have revealed that lay time per vessel is approximately twice as long as case examples show, like Goussiantiner (2009). Admittedly, it cannot be said if this is so for other ports. However, for all calculations in this article the values of the Port of Hamburg are used.

Port lay time is however one of the parameters with the strongest influence on ROI. Smaller vessels, which can handle containers faster in port than larger ships, are better than larger vessels regarding profitability. To take note of earnings alone is

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$, BAF 320 $/TEU, CAF 8%, THC 143 $/TEU, $/EUR 1.32, for container transport within the Asian or European region (W>2) freight rates of the relevant starting continent are used.

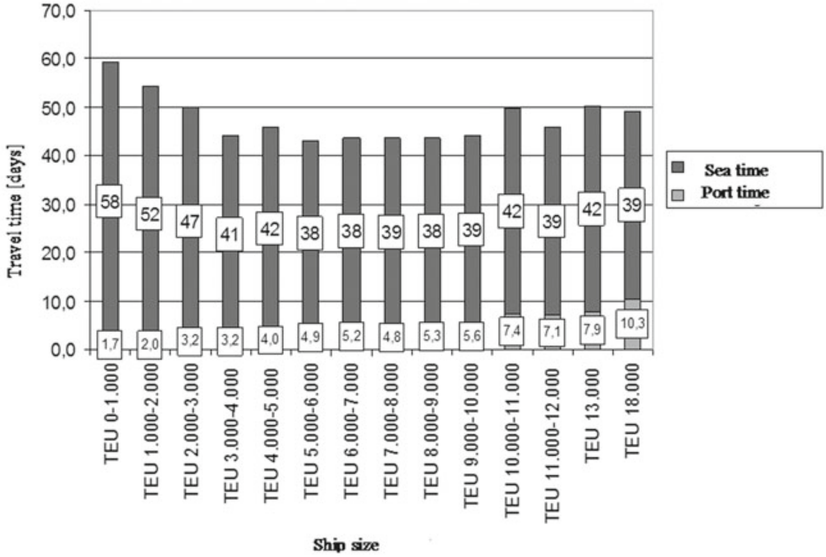

Fig. 11.13 Distribution of time at sea and in port for a loop of 23,000 sm with 10 ports

not enough to judge the profitability of large container ships. Figure 11.13 illustrates how earnings can be generated in various time periods.

11.3.3.2 Evaluating Performance

A ship's performance can be defined in various ways. In the scope of this study performance or productivity, respectively are defined as profit per time unit.

$$P_R = \frac{R_R}{T_R}$$

Earnings shown in Figure 11.12 result in the productivity shown in Figure 11.14. It is clearly seen that ships from 7,000 to 9,000 TEU show the highest productivity. These ships, relatively seen, earn more money per time unit. Productivity can also be broken down into individual slots per ship. It also shows that these types of ships are able to use their slots most frequently per year. Due to the frequency of use, slot productivity is higher than with bigger and smaller ships. Profitability and productivity can be considerably influenced by the following, non-monetary parameters:

- Average container weight affects net slot numbers $NTEU_S$
- TEU factor F_{TEU}, affects stowage structure and therefore the number of handling moves
- Imbalance Q_R, affects full container volume
- Utilization α, affects total container volumes

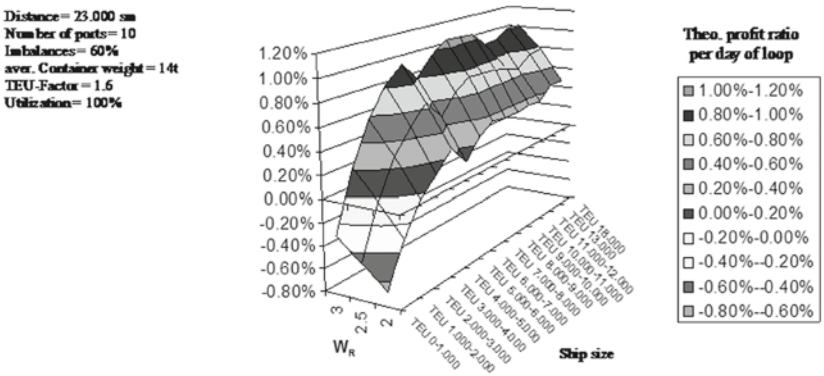

Fig. 11.14 Productivity comparison between various types of ships in 2008 based on Figures 11.1 and 11.13

- Reactivation W_R, affects total container volumes
- Length of the handling process T_{UM} per quay crane affects port lay time
- Number of quay cranes in use N_{CB}, affects port lay time

A detailed discussion of all these parameters is shown in Schönknecht (2009). Except for the first parameter, none of the others have anything to do with the size of the ship. Even the first parameter is determined by trade and cargo development and is not within the power of a shipping line or shipyard. In so far as discussions on the profitability or unprofitability of a ship are about its size alone they will not fulfill the aims but are rather secondary.

A parameter not mentioned explicitly up to now is the number of ports of call in a round trip. The number of ports of call does not affect handling time. It does not matter if all containers are loaded and discharged in one port or spread between five, for example. Pure handling time is theoretically identical. Merely through arrival time and port charges a slight time delay and added costs can arise, although these work out considerably lower than handling time and quay tariffs.

Admittedly, by far not all ports in the world are equipped to handle large container ships. With increasing size, the ships limit more and more the number of ports they can reach. Limiting factors here are port draft, as well as the reach of the quay cranes over the container bays. In this respect, the container bay height, a factor almost disregarded up to now, is to be added. To reach a 10-high container stack on deck (13,000 TEU ship fully loaded) presents an almighty challenge to the container quay crane designers and hydraulic engineers.

Without knowledge of the reasons behind limitations in a port, it can be stated as a result that the giant container ships must be limited to fewer ports as smaller ships. Giant container ships cover a smaller trade route area than smaller vessels. This creates a considerable repercussion in the ports which belong to the loops of the giant container ships. The handling volumes per each departure will disproportionate increase by the effect of the larger container ships and the fewer ports of the loops.

In this context the further research of efficient container terminal operation and hinterland integration is very important. However, the potential concentration of more containers per each departure with increasing ship size shows some parallels to the development of the giant tanker as mentioned at the beginning of this article. The tanker size development up to the ultra-large crude carriers was also characterized by a drop of operational ports. That was unproblematic so long as the cargo, respective the crude oil was refined close to the ports. Distribution (feedering) of crude oil from the main ports to further regions was not necessary. Other regions have been served directly from the crude oil source ports by smaller tankers. But due to the oil crises by the end of the 70th, the procurement behavior of refineries changed. At once the monetary value of the crude oil was very important. Stock volumes were reduced and order volumes were separated into more points of discharge with the consequence that the giant tanker had to distribute the crude oil to more ports than before. And for this process the giant tankers were not suitable. Within some years nearly all super tankers were scrapped.

11.4 Repercussions of the Development of Ship Size on the Transport Chain

In the light of research done up to the present time it can be said that factor Δ from Figure 11.3 will develop over-proportionally to ships growth when large container ships have similarly high profitability and productivity as smaller ships should show. Large container ships must use their slots in less ports just as often as smaller ships use theirs in more ports. This only works when the ships can handle more containers per port. Empirical studies carried out in the Port of Hamburg support this statement. (see Figure 11.15)

This development will not remain an isolated phenomenon for a few ships. If the larger ships prevail, then the ports that deal with these vessels will expect strong peak volumes. This high volume of containers will mean new challenges on storage, as well as collection and distribution of containers (see Pawellek and Schönknecht (2006). At present, there is a danger of delay in container throughput which can be very detrimental, especially for high-value cargo. Considering marginal values with the cost and performance model leads to the insight that combined services of large and small vessels have no chance on trade routes, which can be directly covered by smaller container ships as well. For example, transporting cargo from a large container ship from the Far East to be discharged in Rotterdam and then carried by sea to Hamburg would be too expensive in comparison with a smaller vessel going directly to Hamburg. The marginal profitability advantage of the larger container ship does not pay enough to finance on-carriage.

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[8] HPA – *H*amburg *P*ort *A*uthority, HPA records every ship departure with time stamps including handling volumes in TEU according the German traffic statistics law.

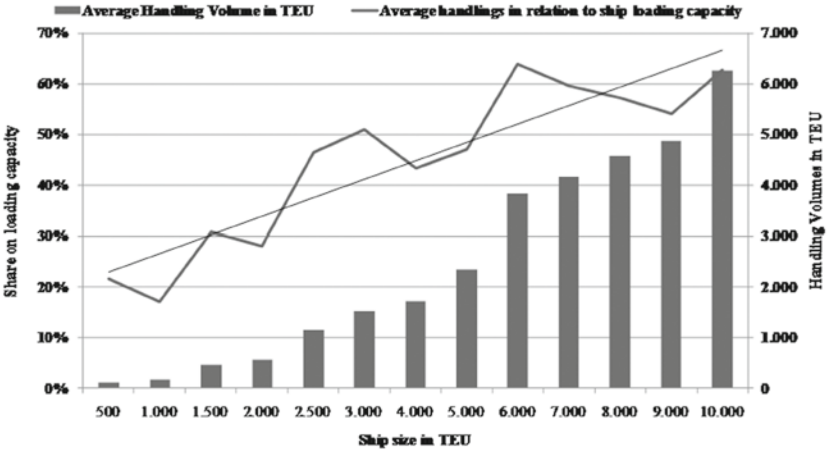

Fig. 11.15 Observations of the factor Δ in the Port of Hamburg; based on database HPA[8]

In a converse argument however, cargo from large container ships must almost entirely be for transport into the hinterland when the profitability of these vessels should be greater than that of smaller ones. Development of peak container volumes in the hinterland will then continue.

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Part IV
Planning Area
Terminal Yard

Chapter 12
Planning Container Terminal Layouts Considering Equipment Types and Storage Block Design

Jörg Wiese, Leena Suhl, and Natalia Kliewer

Abstract
Currently, several container terminals are being expanded, redesigned or newly built. In all those cases the layout of the container terminal has to be designed. We discuss different technologies which can be used for container terminal operation and describe their impact on the terminal layout. Different container terminal layout categories are defined. For a layout which is typical for the use of automated rail-mounted gantry cranes we propose a procedure to calculate promising storage yard configurations. The results show that smaller block widths lead to higher yard performances, but also to higher cost. Using the proposed block design problem, we are able to calculate all non-dominated solutions, which enables terminal planners to choose a solution for their specific situation. Moreover, we analyze the impact of the reefer racks distribution on the yard performance. The results show that an equal distribution of reefer racks over the existing storage blocks allows the best workload distribution.

12.1 Introduction

Looking on terminal planning on a long-term basis, different aspects have to be considered. In particular when a terminal is newly built several planning tasks have to be fulfilled. Terminal planners have to decide, *e.g.* about the terminal capacity, the

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size of the terminal, the used types of equipment and their size as well as the terminal layout. Similar aspects have to be considered when a terminal is reorganized. For example, terminals which operate at their capacity limit can be reorganized in order to increase the handling capacity. In this paper we mainly focus on aspects of terminal layout planning. The decisions about the terminal capacity and the types of equipment used influence the design of a terminal layout. Especially those used for terminal operation in the storage yard predetermine possible layout structures. Likewise the design of a terminal layout might influence the size of equipment. An efficient terminal layout could achieve the same performance using less equipment compared to an inefficient layout. Therefore, we discuss the mutual effects of the different design processes in the context of terminal capacity, equipment and layout planning.

A sample container terminal layout structure is depicted in Figure 12.1. We distinguish between three different parts of a terminal: the seaside, the storage yard and the landside. The seaside layout is defined by the berth length, the number of quay cranes and the distance between quay and storage yard (apron). The storage yard layout is composed of storage blocks and driving lanes. Depending on the yard technology the storage blocks can be arranged perpendicularly or parallel to the quay (see Brinkmann (Chapter 2 of this Handbook)). A parallel block layout is shown in Figure 12.1. Finally, the landside layout consists of a gate where trucks enter and leave the terminal, of truck lanes where external trucks are handled, and of rail tracks where trains are handled. The landside layout facilities are optional as, *e.g.* not all terminals have a rail connection or are linked with the road network (in case of pure transshipment terminals). The horizontal transport system in Figure 12.1 illustrates the transport of containers by horizontal transport equipment between quay and storage yard, as well as between storage yard and landside interfaces, such as rail tracks.

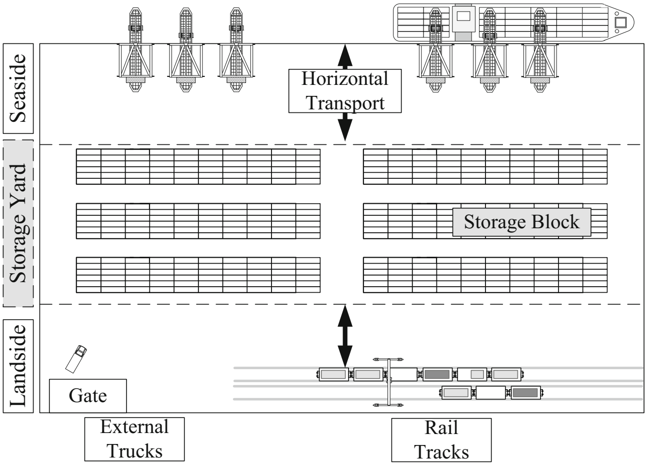

Fig. 12.1 Sample container terminal layout structure

The equipment used for stacking operations has the greatest impact on the layout design. Therefore, we define in this paper categories of container terminal layouts based on typical stacking equipment. Moreover, we describe publications dealing with aspects of terminal layout planning and discuss their results. For a storage yard where blocks are arranged perpendicularly to the quay wall we propose a method to design the storage yard. The trade-offs between cost and performance are discussed. The remainder of the paper is structured as follows: The next section describes possible types of equipment and their influence on the layout. In Section 12.3 possible options to structure the storage yard are described. Moreover, existing publications dealing with aspects of terminal layout planning are discussed. Section 12.4 describes a procedure to determine block designs. Therefore, we propose equations to calculate the expected cycle times of gantry movements and propose a method how to use those equations to calculate yard configurations. Section 12.6 summarizes the results and gives an outlook on further research.

12.2 Equipment Types and Terminal Layout

In this section the possible types of equipment for each part of the terminal are described. Their influence on the layout and the layout design process is explained.

12.2.1 Seaside

In most container terminals *S*hip-*T*o-*S*hore gantry cranes (so-called STS cranes) are used for (un)loading operations of containers onto(from) vessels. A first step in the design process of a terminal is to determine the needed seaside capacity, *i.e.* the berth length and number of quay cranes (usually of STS type) needed to achieve an envisaged capacity. The basis for this calculation usually forms a forecasted schedule of vessel arrivals (so-called vessel call pattern) and a (minimum) throughput target per quay crane postulated for the considered planning horizon. Based on these values simulation studies can be carried out to determine the seaside capacity (see, *e.g.* Ficke and Schütt (2008) and Brinkmann (2005)). The main influencing factors of the quay crane performance (*i.e.* container moves per hour) are on the one hand the technical characteristics of the STS cranes and on the other hand the adequate service of cranes by the seaside transport system performing the horizontal transfer of containers between quay wall and yard. Within the scope of layout planning both aspects have to be taken into account appropriately. That is, the seaside layout, the layout between quay wall and storage yard, has to be configured to attain a high seaside performance. Therefore, the seaside layout configuration has to allow a smooth operation of the horizontal transport and to consider the characteristics and restrictions of the selected STS crane technology.

For instance, a substantial influence on partitioning of space in the portal and backreach of STS cranes and for that reason on the seaside layout has the hoist technology used for (un)loading operations. If cranes possess a dual hoist system, a second trolley exists that decouples the (un)loading process of the (seaside) trolley from the horizontal container transport (see Stahlbock and Voß (2008)). Due to space requirements for handover positions in the backreach, quay cranes of this type usually buffer hatch covers, lashing gear etc. between the crane legs. Additional layout requirements arise if STS cranes are equipped with tandem spreaders (see Stahlbock and Voß (2008)). Such STS cranes are able to handle two 40 ft or four 20 ft boxes simultaneously which has to be considered in particular for dimensioning of container handover positions as space requirements of horizontal transport increase. In addition to the layout requirements of both systems they have the advantage of an increased potential for a high seaside performance. For example, the above mentioned decoupling of the (un)loading process from the horizontal transport by a dual trolley can avoid costly traveling and handover activities at the seaside.

Besides STS crane technology, a punctual service of quay cranes by horizontal transport equipment represents a necessary prerequisite for a high level of crane performance. When waiting times occur the seaside performance decreases. Therefore, layout configuration between quay crane operations area and terminal storage yard must enable a smooth flow of containers avoiding unnecessary obstructions between transport equipment units. Qualitative and quantitative dimensioning of manoeuvring area (especially driving lanes, waiting and/or parking positions for transport vehicles) have to fit the specific requirements of the transport system, as well as the necessities resulting from the physical process of container handover to (from) yard stacks (see, *e.g.* Ranau (Chapter 10 of this Handbook)). The latter is primarily determined by the respective storage system and its mode of operation. The former is determined by the used horizontal transport systems. For these systems, the differences in space requirements are especially induced by the single equipment units and their technical characteristics (such as vehicle length and width or turning radius) as well as the traffic rules for basic control of transport vehicles.

In addition to the qualitative and quantitative dimensioning of manoeuvring area, the selected type of horizontal transport technology might have an influence on the seaside performance. We categorize the horizontal transport technology in active and passive transport technologies. Active transport technologies are able to lift containers by themselves and do not have to be served by a crane. These active transport technologies enable the operator to decouple the handshake processes between horizontal means of transport and quay cranes or between horizontal means of transport and yard cranes. Again, this might influence the quay crane performance. Common active transport technologies are *S*traddle *C*arriers (SC), forklift trucks and reachstackers, for instance. Popular passive transport technologies are terminal trucks (chassis systems) and multi trailers. Currently, in highly automated terminals *A*utomated *G*uided *V*ehicles (AGV) are used for horizontal transport.

For automated transport technologies like AGVs or automated SCs (see, *e.g.* Annala (2007)) security issues have to be considered when planning a terminal layout: No humans are allowed to access the area where such type of equipment is in operation. Therefore, additional organizational requirements have to be considered on planning a layout in case of automated transport technologies. To sum up, different STS crane technologies and container transport operations systems have different space requirements and thus influence the layout of a container terminal significantly. Further technical and logistic details about terminal equipment are given by Brinkmann (Chapter 2 of this Handbook).

12.2.2 Storage Yard

In the storage yard containers are stacked upon each other for temporary storage. In few terminals a wheeled storage of containers is implemented, where containers are stored on chassis in the yard and no stacking occurs. Stacking of containers can be done by using various equipment technologies: A possible type of equipment are active transport technologies (mainly SC systems) which are described in Section 12.2.1. Besides, several types of gantry cranes are popular yard equipments. Those are *R*ubber-*T*yred *G*antry cranes (RTG), *R*ail-*M*ounted *G*antry cranes (RMG) and *O*ver*H*ead *B*ridge *C*ranes (OHBC) (see Brinkmann (2005)). In addition, *A*utomated *R*ail-*M*ounted *G*antry cranes (A-RMG) are newly used in container terminals. A survey of 114 terminals all over the world focused on large seaside container terminals published by Wiese et al (2009a) shows that the most popular yard equipment is the RTG system used in 63.2% of the terminals. It is followed by the SC system with a ratio about 20.2%. Table 12.1 gives an overview of yard equipment used. The column “Main Region” depicts the region where most of the yard equipment installations of the corresponding type can be found. “Frequency in region” describes the number of the terminals in the main region using the corresponding equipment type. The main region where RTG systems are implemented is Asia. Modern technologies using A-RMG systems are mainly implemented in Europe. More information about the survey can be found in Wiese et al (2009a).

A future development could be the use of *A*utomated *S*torage and *R*etrieval *S*ystems (AS/RS) for the storage of containers. AS/RS systems are warehousing systems usually consisting of racks for the storage of items and cranes operating between those racks (see Roodbergen and Vis (2009)). Asef-Vaziri et al (2008) study the potential use of such a system for container terminals in a simulation study. Hu et al (2005) propose a modification of a standard AS/RS (called split-platform AS/RS) which is appropriate for heavy loads and thus could be used for the storage of containers. They develop a travel-time model for the new system and use this model to compare the performance of the modification to the performance of the standard system. Hu et al (2008) introduce a complete yard layout for the split-platform AS/RS and present a novel yard space allocation policy for such a system.

The various types of equipment have different characteristics (*e.g.* maximal possible stacking height and velocities) which influence the equipment decision. Again simulation studies comparing different configurations are published in literature: Vis (2006) compares the performance of a SC system and an A-RMG system by means

Table 12.1 Terminal yard equipment statistic (see Wiese et al (2009a))

Yard Equipment	Frequency	%	Main region	Frequency in region
RTG	72	63.2%	Asia	40
SC	23	20.2%	Europe	15
A-RMG	7	6.1%	Europe	6
Wheeled	2	1.8%	America	2
RTG / SC	2	1.8%	Asia	2
Reachstacker	2	1.8%	Europe	1
RTG / RMG	2	1.8%	Europe	1
automated SC	1	0.9%	Australia Pacific	1
RMG	1	0.9%	Asia	1
RTG / A-RMG	1	0.9%	Asia	1
OHBC	1	0.9%	Asia	1
Σ	114			

of simulation. Both systems are assumed to have pickup and delivery points at the end landside and seaside end of the block. As objective, the average total traveling time of the SC or A-RMG is defined for a scenario considering the storage of 10 containers into a block assuming the same block structure for both equipment. Saanen and Valkengoed (2005) compare the performance of three different A-RMG systems, namely single RMG, twin RMG and cross-over RMG. For the comparison of the A-RMG systems they simulate a system with a single block as well as the whole terminal operation (in a perpendicular block layout). For the single block simulation the objective compared is the number of boxes per hour moved by the respective A-RMG and the occurred delays in case of a twin RMG or cross-over RMG. Additionally, they consider truck service times and a seaside performance measured in quay crane moves per hour for the whole terminal simulation.

Using a specific equipment affects the yard layout in several ways. As the storage yard makes up the major part of the terminal the yard layout is important on designing a container terminal layout. The layout is influenced by the storage equipment in the way the equipment restricts the possible block structure. A block is defined by the number of rows containers are stacked in parallel with each other, by the number of bays, by the number of tiers containers are stacked on each other and by the space needed between bays and rows. Figure 12.2 shows different block structures for possible equipment types. As the figure shows a SC or automated SC system needs more space between the rows compared to a gantry crane system. Additionally, the maximal number of tiers in a SC system is restricted to currently available 4 tiers SCs (see Kalmar Industries (2010)). RTG and RMG systems available can stack containers up to 7 tiers high (see ZPMC (2009)). Gantry systems differ, additionally to the above mentioned characteristics, in their options of transferring a container from the stack to the means of transport. Possible options are transfer points at the beginning and the end of the storage block or a transfer lane parallel to the container rows (see Figure 12.2). The transfer lane option is common for RTG systems, as RTGs are not able to gantry properly while carrying a container (see Petering and

Murty (2009)). RMG systems have the ability to combine both options, *i.e.* using transfer lanes and transfer points. The advantage of RTGs comparing to RMGs is their flexibility, as RTGs can move to other storage blocks, whereas RMGs are fixed to the implemented rails.

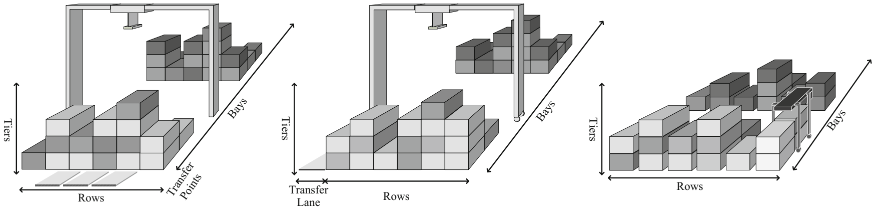

Fig. 12.2 Blockstructures for an RMG with transfer points, for an RTG with transfer lane and for a SC

Due to the different stacking capabilities, different stacking densities can be achieved by each of the above described systems. Chu and Huang (2005) review existing approaches to determine the handling capabilities of container terminals and propose an equation to calculate the area needed for a *T*wenty-foot container *G*round *S*lot (TGS) for different yard sizes and used types of equipment (SC, RTG and RMG). Based on data of Taiwan container terminals, for each equipment different dimensional characteristics are identified. Using the equation and the dimensional characteristics they are able to determine the total number of TGSs for different storage yard sizes, for different handling equipment, and for different block configurations (number of rows of a block). Based on the value of the total number of TGSs, the average dwell time and the maximal number of stacking tiers they are able to calculate the maximal annual container handling capacity of a storage yard (TEU/year). Brinkmann (2005) presents a study in which the needed storage capacity is approximately calculated based on the envisaged annual container turnover, the average dwell time, and a peak factor. For a more precise calculation of the storage capacity a simulation study is carried out in which a maximal occupancy rate is considered. For different types of equipment (SC, RMG, OHBC) the average area needed for a TGS is calculated based on the determined storage capacity.

On the one hand, these methods can be used on planning a terminal to determine the needed yard capacity and the needed area for the storage yard (respectively the needed number of ground slots) for a specific type of equipment based on a planned annual handling capacity. On the other hand, these results can be used to limit the possible equipment alternatives: Having limited space for the planned terminal some technologies might be impractical. For example, having a high planned annual capacity and less space available for the storage yard, the use of a SC system could be impossible.

12.2.3 Landside

At the landside area trains as well as external trucks are handled. When a gantry system is used for stacking operations no special equipment for the handling of external trucks is needed. The trucks can be handled directly by the gantry crane at the assigned storage block. In active transport technology systems (*e.g.* SC systems) a truck service area is needed, where trucks wait to be handled by an active means of transport. The active means of transport picks up a container at the storage block and carries the container to the truck service area, where it loads the waiting truck.

Between the rail tracks and the storage yard a horizontal transport is needed. Here the equipment described in above Section 12.2.1 can be used. When an active transport technology is used for horizontal transport, it can also be used to load and unload trains. A popular equipment technology used for train handling is a RMG system which spans the rail tracks. A new variant of landside operation is analyzed in Froyland et al (2008): They propose an optimization procedure for a RMG system. This system consists of multiple RMGs operating on rail tracks, an intermediate stacking area and a road interface. Thus, the system is able to handle trains and trucks simultaneously. Such a configuration is implemented at Port Botany in Sydney.

Similar to the seaside, a landside capacity has to be planned. Based on a forecast of truck and train arrivals the capacity of the landside facilities like gate and rail tracks has to be calculated (see Liu et al (2002)). Therefore, the number of lanes and the number of rail tracks should be determined, which then determines the size of these facilities.

12.2.4 Terminal Layout Planning Problem and Impact Factors

In the sections above the relationship of the different planning tasks, especially the relationship between layout planning and equipment selection, is described. Moreover, we discuss how the determination of seaside, yard and landside capacity influences the layout planning. In this section we summarize the influences and describe a possible process of planning a container terminal layout. Figure 12.3 illustrates the planning tasks, layout planning and equipment selection as well as seaside, yard and landside capacity planning and their influences on each other. The process of layout planning can be subdivided into yard layout, seaside layout and landside layout planning, while yard layout planning itself has the subproblem of designing storage blocks.

The first step of the terminal planning process is to determine the seaside capacity. Subsequently, the needed landside and yard capacities are derived from the prior calculated seaside capacity. Thus, both capacities have to be dimensioned for the handling of the container flow extrapolated from the seaside capacity (see Section 12.2.1). The different capacities influence the corresponding different equipment selection problems, which in turn influence the layout planning problem. For instance, the block design problem and therefore the yard layout problem is influenced by the selected yard equipment. The yard equipment itself is restricted by the yard capacity (see Section 12.2.2). The structure of the driving lanes is influenced by the selected transport equipment. The seaside layout is influenced by the transport equipment (required size of manoeuvring area) and additionally by the seaside capacity which specifies the berth length. The landside layout is influenced by the needed landside capacity which specifies, *e.g.* the needed number of truck lanes or the number of rail tracks.

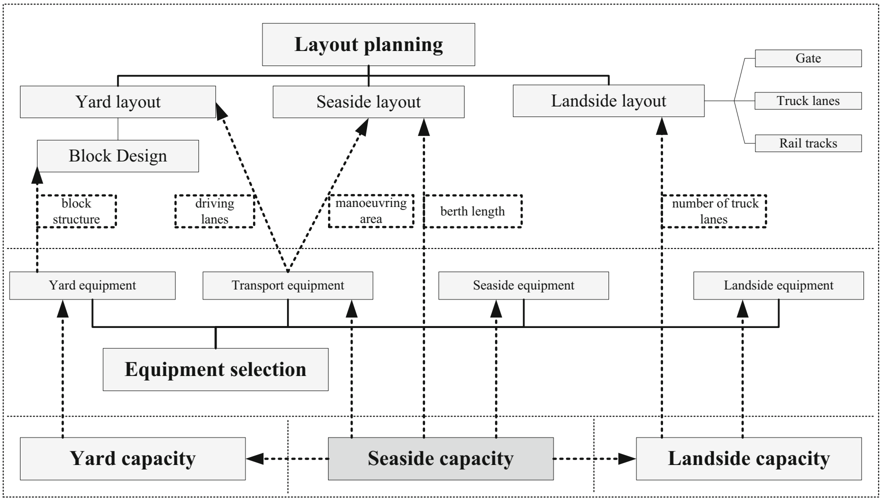

Fig. 12.3 Relationships of the different planning tasks: layout planning, equipment selection as well as yard, landside and seaside capacity planning

As a consequence, the planning tasks of equipment selection, of determining the seaside, yard and landside capacity have to be carried out before the layout planning. When these tasks are finished, the information gained is used for layout planning: One part of the seaside layout can be defined using the berth length resulting from the seaside capacity as well as considering the restrictions of the selected STS crane technology. The remaining part of the seaside layout, the manoeuvring area, can be defined using the information about the chosen transport equipment and the seaside capacity. The chosen transport equipment and the seaside capacity is used to conduct the needed number of driving lanes and parking positions, which compose the manoeuvring area. For defining the landside layout, the gate, truck lanes and rail tracks have to be positioned. As the landside connection of rail tracks and streets have to be considered, the possible placement positions could be restrictive. Nevertheless, a modified facility layout planning model published by Wiese et al (2009b) could be used to find optimal positions for *e.g.* the gate.

The remaining problem is to determine the yard layout. The yard layout problem is to organize the yard with its components: the storage blocks and the driving lanes.

The characteristics of the driving lanes are defined by the selected transport equipment. A block is defined by the block structure and the number of rows, bays and tiers used for stacking (see Section 12.2.2). The block structure is determined by the used equipment type and, more important, by the options for transferring a container between the stack and the horizontal means of transport. Defining block characteristics such as the width of the storage blocks considering a given block structure can be seen as a subproblem of the yard layout planning problem, the block design problem. The yard layout planning and the block design problem are examined in the following sections.

12.3 Container Terminal Yard Layouts

In this section the yard layout problem is discussed. The storage yard layout is defined by the organization of the driving lanes, by the number of driving lanes, by the orientation of the storage blocks, the block structure, and the design of the storage blocks. The orientation of the storage blocks can either be perpendicularly or parallel to the quay. The layout of storage blocks is defined by the used block structures (Section 12.2.2) and the block design. According to block structures and to the orientation of the storage blocks, container terminal layout categories can be defined. Figure 12.4 shows two typical layout categories each having a different block orientation. The first layout in Figure 12.4 displays a layout with blocks that run parallel to the quay and a transfer lane at each block. This is a very common layout when RTGs are used for stacking operations. The second layout is a perpendicular layout of blocks, where transfer points at both ends of the blocks are used. Frequently, this layout is used in combination with RMGs or A-RMGs for stacking operations. Additionally, for transfer lanes or for transfer points, either a perpendicular or parallel option is possible. When using active transport technologies for stacking no transfer points or lanes are needed. Nevertheless, the rows in which the containers are stored can either be arranged parallel or perpendicularly to the quay. In some terminals, like the container terminal Burchardkai in Hamburg, a mixture of parallel and perpendicular blocks with no transfer option exists. The study of Wiese et al (2009a) shows that in about 90% of the cases where RTGs are used for stacking a parallel layout with transfer lanes is used. Furthermore, the study shows that in 6 out of 7 cases a perpendicular layout is used for A-RMG systems.

In the second layout in Figure 12.4 the seaside transport and the landside transport are separated by storage blocks. Thus, external trucks are handled at the landside end of the storage blocks. At the seaside end of the storage blocks the traffic to the quay is handled.

In current literature three studies examine the problem of determining the orientation of storage blocks for an RTG yard layout. Simulation is used by Liu et al (2004) and Petering (2008), whereas Kim et al (2008) derive formulas to calculate

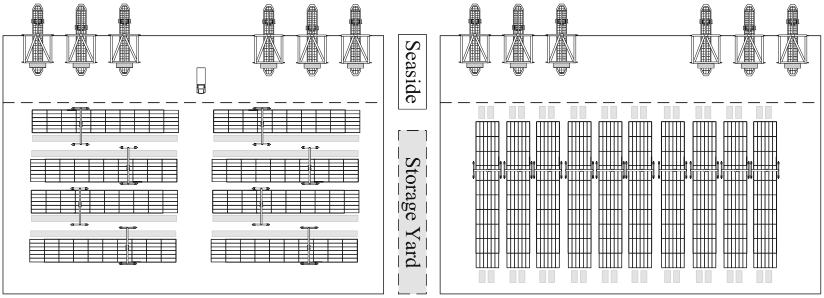

Fig. 12.4 Parallel layout with transfer lanes and perpendicular layout with transfer points

the expected traveling distances for trucks and the expected number of rehandles[1]. Liu et al (2004) and Petering (2008) both simulate transshipment terminals, where no landside connection of the terminal is considered. In contrast Kim et al (2008) examine the layout configurations for a terminal having a landside connection through a gate. Petering (2008) consider different performance measures during the simulation study, like quay crane rate or productivity of RTGs and trucks. The quay crane rate is defined as average number of moves that a quay crane performs during operation at a busy berth. Similar, Liu et al (2004) track different performance measures, *e.g.* the quay crane rate and idle times of the equipment. Kim et al (2008) come to the result that parallel layouts are superior to perpendicular layouts in respect to their objective which considers the costs for the expected average traveling distance of trucks and the costs for performing the expected number of rehandles using RTGs. Conversely, Liu et al (2004) come to the result that under their assumptions the perpendicular layout is superior with respect to quay crane moves and number of horizontal transport equipment needed. Petering (2008) indicates that parallel layouts are preferable to perpendicular layouts. Nevertheless, the results in Petering (2008) show that in some cases a perpendicular layout outperforms a parallel one considering the different performance measures (especially the quay crane rate). In summary, the present studies for blocks with transfer lanes do not come to a consistent result that one orientation is clearly superior compared to another orientation. However, in the real world situation about 90% of the terminals using RTGs have a parallel layout (see Wiese et al (2009a)).

12.4 Storage Block Design

As mentioned above the block structure influences the yard layout and thus the layout of a container terminal. We are aware of the following three publications that deal with the determination of the block design for an RTG yard layout. Petering

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[1] Rehandles are unproductive moves which have to be executed by cranes to retrieve a container which is stored under other containers.

and Murty (2009) and Kim et al (2008) analyze, beside others, the influence of the block length (number of bays) on the terminal performance in case of a parallel layout with transfer lanes (see Figure 12.4): Petering and Murty (2009) use a comprehensive simulation study to analyze the influence of the block length as well as the influence of yard crane deployment systems on the overall terminal performance of a pure transshipment terminal. Kim et al (2008) analyze, besides orientation options, the optimal length of storage blocks. The results of both studies can hardly be compared as Kim et al (2008) follow an approach where in all cases the terminal area is constant and the stacking height is variable, whereas Petering and Murty (2009) assume an approach where the terminal area is variable and the stacking height is constant. Furthermore, Petering and Murty (2009) examine a pure transshipment terminal and thus do not consider landside connection. In contrast Kim et al (2008) consider external truck traffic through a gate.

Furthermore the third one, Petering (2009), analyzes the influence of different block widths on the terminal performance. Again, Petering (2009) uses a comprehensive simulation model for the analysis of a transshipment container terminal. The yard layout is defined as a parallel block layout with transfer lanes. Different block widths between two and fifteen rows are simulated for a small and large terminal setting. Furthermore, Petering (2009) considers for each terminal setting a scenario in which more respectively less equipment (number of trucks, RTGs) is deployed. The different simulated layout configurations are compared with respect to the quay crane rate. The results indicate that the optimal block width ranges from 6 to 12 rows depending on the terminal setting and equipment scenario used.

In the following sections we present a procedure to calculate configurations of storage yards and their block designs in a perpendicular layout with transfer points as depicted in Figure 12.4. Thus, we assume that the blocks are orientated perpendicularly to the quay and the landside traffic is separated from the seaside traffic. External trucks are handled only by the landside transfer points, whereas the seaside traffic is handled by the seaside transfer points. Those layouts can be frequently found in major ports in Europe, *e.g.* the CTA in Hamburg or the ECT in Rotterdam implement such a configuration. Following Wiese et al (2009a) six terminals in Europe use or plan to use A-RMG configurations. In the CTA and the ECT terminals AGVs are used for the seaside horizontal transport and an A-RMG system in the storage yard. In such layout configurations reefer racks are positioned at the landside end of the blocks. Service workers need easy access to the reefer containers, and therefore it would be impractical to position the reefer racks, *e.g.* in the middle of the blocks. Furthermore, we assume that the gantry cranes operate in single cycle mode where the crane goes empty into the block, collects a container and goes back to the transfer point and vice versa for storing a container. Additionally, gantry moves and sideward movements of the trolley can be done simultaneously. We assume that the time spent on gantry moves is greater than the time for sideward movements of the trolley. Therefore, we neglected the time for sideward movements of the trolley.

12.4.1 Cycle Distance of Gantry Movements

In this section approximate estimates for the expected average cycle distances for storing a container into a block or for removing a container from a block and to return for the next task are derived for a single A-RMG. The expected distances depend on the length of a block, the number of reefer racks in the block and the ratio of containers to be handled either at the seaside or the landside transfer points. The following variables and parameter are used for the calculation of the expected cycle gantry distance d_g^t where $t = \{STD, REEF\}$ denotes the container type to pickup. α denotes the probability that a container has to be moved from or to a seaside transfer point. Likewise β denotes the probability that a container has to be moved from or to a landside transfer point. Naturally, $\beta = 1 - \alpha$. In other words α and β can be calculated using the ratios of import, export and transshipment of a terminal. Every import or export container passes through the terminal using both sides of a block (seaside and landside). In contrast transshipment containers are stacked into a block and retrieved from a block only via the seaside. Thus, in a pure transshipment terminal α would be one. For all terminals α is between 0.5 and 1 depending on the transshipment ratio of the specific terminal. w denotes the width of a block in rows and l the length in bays. r is the number of reefer racks at the landside end of a block. The considered possible cycle moves for a gantry are illustrated in Figure 12.5.

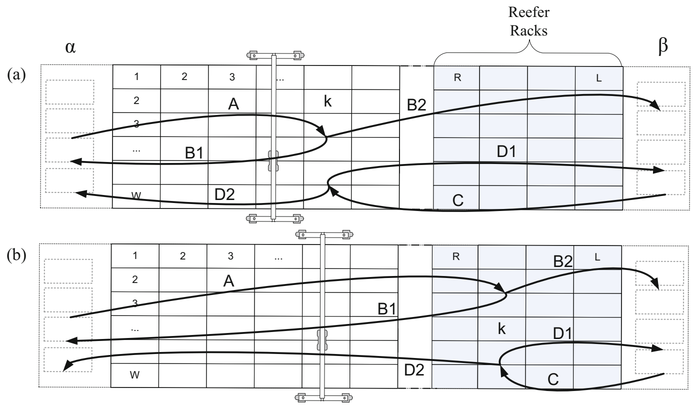

Fig. 12.5 Possible cycle moves for (a) standard containers (b) reefer containers

Using the probabilities α and β we are able to describe the likelihoods for all cycles displayed in Figure 12.5. In the following we assume that the probability that a crane has to move to a specific bay (to store or retrieve a container) is equal for all bays. The probability for a first move A is α and for C is β. The probability that move B1 or B2 follows after move A as well as the probability that move D1 or D2 follows after C depends again on the probabilities α and β. For example the likelihood for cycle (A,B2) is $\alpha \times \beta$. The expected distance for standard containers is calculated as follows: A possible cycle move is (A,B1) having a distance $2 \times k$ with $k < (l-r)$ and $P\{k = 1, \ldots, (l-r)\} = \frac{1}{(l-r)}$. The probability for cycle (A,B1) is α^2. Cycle (A,B2) as well as (C,D2) have a distance $l+1$ and a probability of $\alpha \times \beta$ or $\beta \times \alpha$. The last possible cycle is (C,D1) with a distance $2 \times (k+r)$ with $k < r$, and a probability β^2. The cycles for the reefer containers can be described similarly. All possible cycles are depicted in Table 12.2.

Table 12.2 Expected cycle distances

	Cycle	Distance of cycle	Probability
Reefer:	(A,B1)	$2 \times (l-r+k)$	$\sum_{k=1}^{r} \frac{1}{r} \alpha^2$
	(A,B2) or (C,D2)	$l+1$	$\alpha\beta$
	(C,D1)	$2 \times k$	$\sum_{k=1}^{r} \frac{1}{r} \beta^2$
Regular:	(A,B1)	$2 \times k$	$\sum_{k=1}^{(l-r)} \frac{1}{(l-r)} \alpha^2$
	(A,B2) or (C,D2)	$l+1$	$\alpha\beta$
	(C,D1)	$2 \times (k+r)$	$\sum_{k=1}^{(l-r)} \frac{1}{(l-r)} \beta^2$

By summing up the possible cycles for standard containers, the estimate for the expected average distance can be calculated as follows:

$$d_g^{STD}(\alpha,\beta,l,r) = \sum_{k=1}^{(l-r)} \frac{1}{(l-r)} \alpha^2 2k + \sum_{k=1}^{(l-r)} \frac{1}{(l-r)} \beta^2 2(k+r) + (2\alpha\beta)(l+1) \tag{12.1}$$

$$d_g^{STD}(\alpha,\beta,l,r) = \alpha^2(l-r+1) + \beta^2(r+l+1) + (2\alpha\beta)(l+1) \tag{12.2}$$

Concerning reefer containers, the estimate for the expected average distance can be calculated as follows:

$$d_g^{REEF}(\alpha,\beta,l,r) = \sum_{k=1}^{r} \frac{1}{r} \alpha^2 2(l-r+k) + \sum_{k=1}^{r} \frac{1}{r} \beta^2 2k + (2\alpha\beta)(l+1) \tag{12.3}$$

$$d_g^{REEF}(\alpha,\beta,l,r) = \alpha^2(2l-r+1) + \beta^2(r+1) + (2\alpha\beta)(l+1) \tag{12.4}$$

12.4.2 The Block Design Problem

Based on the equations (12.2) and (12.4) presented above we propose a procedure to optimally structure the blocks in the storage yard in the case of a perpendicular layout with transfer points. In practice the width w and the length l of a block is the same among all installed blocks in the terminal. Let I be the set of blocks installed on a terminal. For simplification we assume $\forall i, j \in I, i \neq j$ that $w_i = w_j \wedge l_i = l_j$. Moreover, we assume that the reefer racks are equally distributed over the blocks $\forall i, j \in I, i \neq j \; r_i = r_j$. The length of a bay is defined by the length cl and the width cw of a ground slot. We assume that the total width of a block is defined by the width of the rows ($w \times cw$) and by a width δ_1 representing the additional space needed, *e.g.* for rail tracks. In addition we consider a space between two blocks δ_2. At each block operates a single A-RMG crane. We assume a rectangular area available for the storage yard defined by a maximal width W. The terminal depth is not restricted. As mentioned above the seaside and landside traffic of containers has to be handled by the storage yard blocks. We assume a flow F of containers which have to be stacked into the storage blocks in a given time period (*e.g.* one hour). γ denotes the ratio of reefer containers among the total flow F of containers. TGS^t defines for container type t the needed ground slots that have to be accommodated by the storage blocks. The gantry speed of the RMG is defined by v. The number of blocks used in the yard n depends on the used width w:

$$n = \left\lfloor \frac{W + \delta_2}{w \times cw + \delta_1 + \delta_2} \right\rfloor \tag{12.5}$$

δ_2 has to be added to the yard width as the space in between the blocks only occurs $n-1$ times. The area a in m^2 occupied by the blocks is calculated as follows:

$$a = (w \times cw + \delta_1) \times (l \times cl) \times n + \delta_2 \times (l \times cl) \times (n-1) \tag{12.6}$$

The overall width of all blocks is defined by B and is calculated as follows:

$$B = (w \times cw + \delta_1) \times n + \delta_2 \times (n-1) \tag{12.7}$$

The expected distance for horizontal transport depends on the overall width of all blocks B. As we assume that we have a given maximal width W which is more or less occupied by the installed blocks, B just changes slightly for different layout configurations. Furthermore, we assume a uniform distribution of containers among all blocks of the terminal. Due to these facts the distance of the horizontal transport will just change slightly. Therefore, we do not consider the impact of the changes in the expected traveling distances (for the horizontal transport) on the yard performance in this study.

The aim of a terminal operator which designs a container yard is to maximize the performance on the one hand and to minimize his cost on the other hand. We define the following *B*lock *D*esign *P*roblem (BDP):

$$\min_{w} \quad f1: \quad a + n \times c^c \tag{12.8}$$

$$\min_{w} \quad f2: \quad d_g^{STD}(\alpha,\beta,l,r) \times \tfrac{cl}{v} \times \tfrac{F}{n} \times (1-\gamma) + d_g^{REEF}(\alpha,\beta,l,r) \times \tfrac{cl}{v} \times \tfrac{F}{n} \times \gamma + \tfrac{F}{n} \times L \tag{12.9}$$

$$\text{s.t.} \quad n \times w \times (l-r) \geq TGS^{STD} \tag{12.10}$$

$$n \times w \times r \geq TGS^{REEF} \tag{12.11}$$

Objective (12.8) minimizes the cost, where c^c defines a factor representing the ratio of crane costs to area costs. The objective (12.9) minimizes the time needed to store the amount of containers F (either standard or reefer containers) into the blocks. In addition to the pure gantry times estimated by $d_g^t(\alpha,\beta,l,r)$ we consider a constant time per container (L) for additional movements (*e.g.* positioning of containers on the horizontal means of transport or the assigned yard slot) and to model the effect of acceleration and deceleration. The constraints (12.10) and (12.11) ensure that the needed number of ground slots is achieved. We assume that the flow is distributed equally over the blocks and thus we divide the flow by n. By neglecting horizontal transport an equal distribution of containers leads to a high performance of the yard system due to an equally distributed workload. This conforms to dispersion rules for container storage location assignment as described, *e.g.* in Petering and Murty (2009). In practice, however, an equal distribution of the workload might not be possible in each situation. To calculate a solution for the BDP we calculate the needed value of reefer racks r per block:

$$r = \left\lceil \frac{TGS^{REEF}}{n \times w} \right\rceil \tag{12.12}$$

To achieve the needed capacity of TGS we are able to calculate the needed length of the blocks by:

$$l = \left\lceil \frac{TGS^{STD}}{n \times w} \right\rceil + r \tag{12.13}$$

Using a greater length than needed would reduce the performance, because d_g^{STD} and d_g^{REEF} are positive linear functions depending on l. Thus, by using (12.12) and (12.13) we can calculate a valid solution for a given width w of the blocks. As we round up the block length values, different values of w will lead to yard configurations with slightly different numbers of total ground slots. However, the needed number of ground slots are provided by all solutions. Therefore, we do not consider possible effects that might occur due to the slightly different numbers of ground slots. The span of A-RMG cranes and of other gantry cranes are restricted due to technical reasons. We assume a minimal span of 3 container rows and a maximal span of 15 rows. A typical span for an A-RMG is about 10 rows wide. Due to the restricted span of the A-RMG we can easily enumerate all possible values for $w = 3,\ldots,15$ and find solutions for the BDP that are optimal regarding at least one objective.

12.5 Numerical Results and Interpretation

In this section we present numerical results for a typical container terminal configuration. The width W of the terminal is 900 m. The storage capacity is 9450 ground slots with $TGS^{STD} = 9000$ and $TGS^{REEF} = 450$. The space for cranes is $\delta_1 = 4$ m, the distance between blocks is $\delta_2 = 5$ m and length and width of a ground slot are $cl = 6.5$ m and $cw = 2.9$ m. The total flow of containers is $F = 650$. Regarding the performance of the storage yard we assume an average gantry velocity of $v = 3.5$ meters per second. The additional time for hoisting etc. is $L = 35$ seconds. Where we assume 20 seconds for hoisting and lowering of a container and 15 seconds for the time to position a container (*e.g.* in the block or on a means of transport).

Table 12.3 Influence of the different widths ($w = 3, \dots, 15$) on the total width of all blocks (B), on the number of blocks (n), on the length of the block (l) and on the number of reefer rows per block (r)

w block width	3 12.7	4 15.6	5 18.5	6 21.4	7 24.3	8 27.2	9 30.1	10 33	11 35.9	12 38.8	13 41.7	14 44.6	15 47.5
B	898	881	888	893	874	897	873	869	895	871	882	888	888
n	51	43	38	34	30	28	25	23	22	20	19	18	17
l	62	56	51	48	46	44	42	42	40	40	39	38	38
block length	403	364	332	312	299	286	273	273	260	260	254	247	247
r	3	3	3	3	3	3	2	2	2	2	2	2	2

The different values for the number of blocks n, for the block length l, for the total width of all blocks B and for the number of reefer rows per block r when changing the block width w between 3 and 15 rows are displayed in Table 12.3. Naturally, the number of blocks decreases when the block width increases. In all cases an increased block width leads to a shorter or at least identical length of the blocks. The maximal occupation of the available total width of 900 m is achieved by the solution with three rows ($B = 898$ m). In contrast, for a value of $w = 10$ rows only 869 m of the available 900 m are used. Consequently, the low use of the available width has to be compensated by a greater block length, which in this case leads to an identical block length compared to $w = 9$ rows. In other words, some block widths fit better into the available yard width than others.

12.5.1 Distribution of Reefer Racks

For the BDP we assume that the reefer racks are distributed equally over the blocks. In this section we discuss briefly what consequences a non-equal distribution has. We analyze options where a subset of the blocks stores solely standard containers. Variable Q defines the number of blocks i which have no reefer racks. Additionally, we define $R = n - Q$ the number of blocks where reefer racks exist. In this case note that r is redefined as follows:

$$r = \left\lceil \frac{TGS^{REEF}}{R \times w} \right\rceil \tag{12.14}$$

Again we assume that among the R blocks the reefer racks are distributed equally. Furthermore, the number of blocks Q without reefer racks is restricted by

$$Q \leq n - \left\lceil \frac{TGS^{REEF}}{l \times w} \right\rceil. \tag{12.15}$$

In other words, if constraint (12.15) is not satisfied the remaining $n - Q$ blocks are not able to accommodate the needed number of reefer slots (TGS^{REEF}) even if the full block length l is used. Consequently, the possible values for Q can again be enumerated. As we do not aim to analyze the influence of the block width w, the performance of the blocks depending on l remains unchanged. Varying the number of blocks with no reefer racks Q (standard blocks), changes the distribution of the flow, as the reefer containers can only be distributed among the R blocks with reefer racks (reefer blocks). The flow of reefer containers is distributed to these R reefer blocks

$$F^{REEF} = \frac{F \times \gamma}{R}. \tag{12.16}$$

Thus, F^{REEF} is the reefer flow per reefer block. The flow of standard containers can be distributed to all blocks (standard and reefer blocks) that not purely consist of reefer racks. For simplification we assume that the standard flow is distributed based on the ratio of storage capacity provided by the different blocks. Thus, the Q standard blocks and the R reefer blocks have to be distinguished, as a standard block possesses $l \times w$ standard slots in contrast to the $(l - r) \times w$ slots provided by a reefer block. Thus, the flow to the standard blocks is defined as

$$F_Q^{STD} = \begin{cases} \frac{F \times (1-\gamma)}{Q} \times \frac{l \times Q}{l \times Q + (l-r) \times R} & \text{when } Q > 0, \\ 0 & \text{else,} \end{cases} \tag{12.17}$$

and the flow to the reefer blocks as

$$F_R^{STD} = \frac{F \times (1-\gamma)}{n-Q} \times \frac{(l-r) \times R}{l \times Q + (l-r) \times R}. \tag{12.18}$$

Consequently, F_R^{STD} represents the flow of standard containers per reefer block and F_Q^{STD} represents the flow of standard containers per standard block. Hence, the reefer blocks have to handle the total flow $F_R^{STD} + F^{REEF}$ consisting of reefer and standard containers where the standard blocks only process the standard container flow F_Q^{STD}.

First, the flow distribution depending on different values of Q is illustrated. Therefore, we define the used width of blocks $w = 10$ which results in a yard layout with $n = 23$ blocks. We enumerate all possible values of Q and calculate the values for F^{REEF}, F_Q^{STD} and F_R^{STD} considering different values of γ. Figure 12.6 displays the results for $\gamma = 0.2$ and $\gamma = 0.5$.

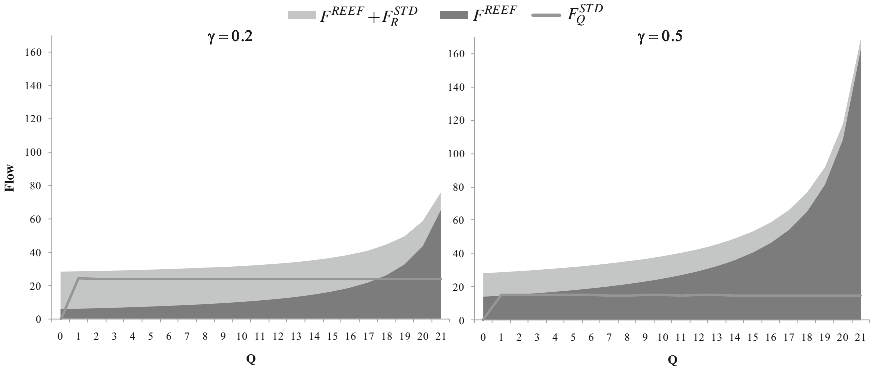

Fig. 12.6 Flow values F^{REEF}, F_R^{STD} and F_Q^{STD} per block for different values of Q and $\gamma = 0.2$ or $\gamma = 0.5$

The results depicted in Figure 12.6 show that an increase of Q and consequently a decrease of R leads to a higher total flow ($F^{REEF} + F_R^{STD}$) per reefer block. The additional flow of standard containers to be processed by a reefer block (F_R^{STD}) decreases for higher values of Q. Thus, for both reefer ratios ($\gamma = 0.2$ and $\gamma = 0.5$) the proportion of standard containers to be handled by a reefer block decreases significantly for higher values of Q. In case of $\gamma = 0.5$ and $Q = 21$ only about 4% of the flow to a reefer block are standard containers (see Figure 12.6). The flow of standard containers to be handled per standard block F_Q^{STD} remains on an identical level for different values of Q. Naturally, this level is lower in case of the higher reefer ratio of $\gamma = 0.5$ compared to the lower ratio of $\gamma = 0.2$. To sum up, in case of high values of Q a comparatively high flow of reefer containers has to be handled by each of the remaining reefer blocks. This might lower the performance of the yard, especially in situations of high reefer ratios (high values of γ). Hence, an equal distribution of reefer racks over the existing storage blocks allows the best workload distribution.

In the following we analyze the impact of the reefer rack distribution on the yard performance. To analyze the performance we consider the performance of the reefer blocks and the standard blocks. Therefore, we need to introduce new estimates to measure the performance of the different block types. First, the time t_R^{REEF} of a reefer block to handle the reefer containers F^{REEF} is calculated by

$$t_R^{REEF} = d_g^{REEF}(\alpha, \beta, l, r) \times \frac{cl}{v} \times F^{REEF}, \tag{12.19}$$

and the time t_R^{STD} to handle the standard containers F_R^{STD} is calculated by

$$t_R^{STD} = d_g^{STD}(\alpha,\beta,l,r) \times \frac{cl}{v} \times F_R^{STD}. \tag{12.20}$$

Second, the time t_Q^{STD} of a standard block to handle the standard containers F_Q^{STD} is calculated by

$$t_Q^{STD} = d_g^{STD}(\alpha,\beta,l,0) \times \frac{cl}{v} \times F_Q^{STD}. \tag{12.21}$$

For an exemplary calculation we assume a peak scenario in which most containers have to be handled on the seaside $\alpha = 0.8$ and the total flow of containers is $F = 400$ which has to be handled in one hour. Furthermore, we assume that half of the containers in the system are reefer containers (*i.e.* half of the quay cranes unload reefer containers). Thus, γ is set to 0.5. Again we assume a block width of $w = 10$ rows. Please note that the calculation of l in (12.13) has to be changed as the number of reefer racks per block r changes for different values of Q. For the sake of brevity we simply set $l = 42$ (see Table 12.3).

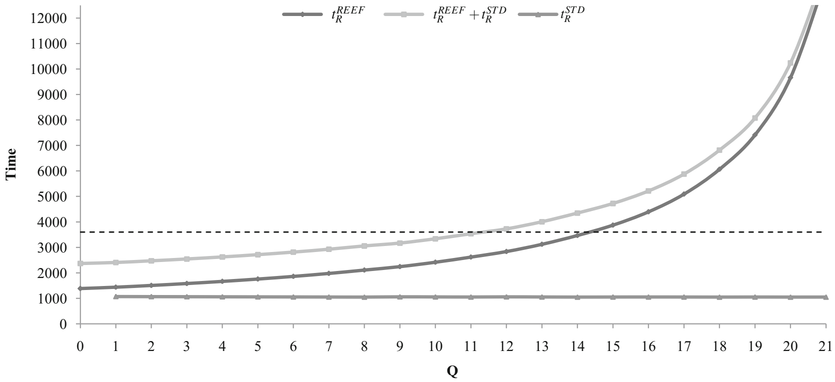

Fig. 12.7 Performance times t_R^{REEF}, t_R^{STD} and t_Q^{STD} for different values of Q and $\gamma = 0.5$

The different performance times for the peak scenario are shown in Figure 12.7. The results show that the change of performance due to different values of Q is obviously similar to the change of flow values in Figure 12.6. For higher values of Q the time needed for a reefer block to handle the assigned number of containers increases as the flow of containers increases. The time needed for the standard blocks stays on a similar level for different values of Q. Thus, the reefer blocks might become the bottleneck in the terminal system. As mentioned above, congestions at the blocks can lead to a reduction of the overall terminal performance. For instance, we assume in this peak scenario that the flow of containers occurs during one hour and thus we have to consider a time limit of one hour (3600 seconds) for each block to handle the container flow (dotted line in Figure 12.7). In case that the time limit is exceeded by a block configuration, congestions occur which reduce the overall performance. In other words, the flow of containers F induced during one hour by quay cranes and by the landside cannot be handled properly by the yard system. For the current scenario solutions with $Q \geq 15$ standard blocks exceed the time limit in case that only reefer containers are handled by the reefer blocks. When reefer blocks additionally process standard containers, a solution with $Q \geq 12$ already exceeds the time limit. In this way the above described method can be used to estimate a valid number of reefer respectively standard blocks for a given performance limit. For instance, a solution with $Q = 11$ standard blocks and thus $R = 12$ reefer blocks would be a valid solution for the given scenario (A solution with $Q = 14$ would be a valid solution in case that only reefer containers are processed by reefer blocks). To sum up, the results show that if high reefer rates occur the reefer racks should be distributed to a sufficient number of blocks. A sufficient number of reefer blocks allow a good distribution of the workload and thus avoid yard congestions.

12.5.2 Calculating Block Designs

First we analyze optimal cost regarding the BDP. Therefore, we neglect the performance values of the different block configurations. Realistic values for the parameter c^c are difficult to determine, and thus we use a broad range of values for c^c between 1 and 10000. First of all, the resulting area costs (a) for different values of w are presented in Figure 12.8.

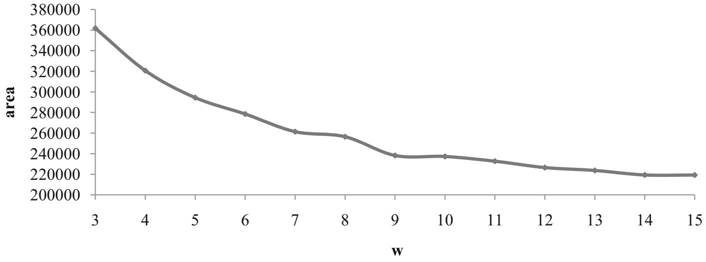

Fig. 12.8 The area (a) for different values of w

Figure 12.8 shows that the occupied area decreases for wider block width as the block length decreases. In case of an increase of the block width from 7 to 8 rows the area occupation stays on a nearly similar level. As already described above this is due to the fact that in case of 8 rows the available total width is used more efficiently compared to a width of 7 rows (see also Table 12.3). Figure 12.9 shows the results when crane costs are additionally considered. Again, the cost decrease for wider block widths for all different crane cost ratios ($c^c \geq 4000$). Smaller block width leads to a higher number of blocks (see also Table 12.3) and consequently to a higher number of cranes and total crane costs. Thus, in most situations a yard configuration with minimal cost uses a great block width w.

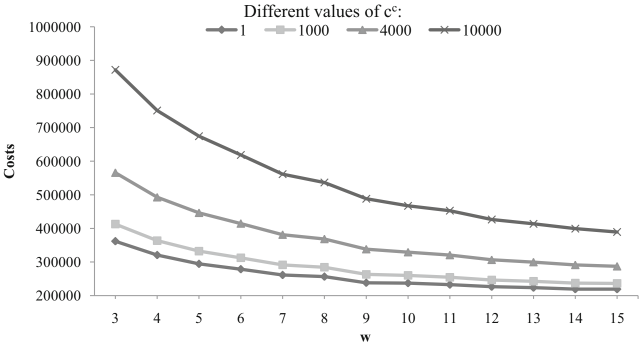

Fig. 12.9 The costs ($f1$) for different values of w and c^c

In the following we analyze the impact of different block widths on the performance. Therefore, we assume that $\gamma = 0.2$. Figure 12.10 displays numeric results of the performance for different values of α. As we assume that at least the seaside traffic equals the landside traffic, we define that $\alpha \geq 0.5$. Using the smallest possible block width w achieves the highest performance. For smaller block widths the flow of containers is distributed to more blocks compared to a solution where wider blocks are used. This effect dominates the effect that the traveling distances of the gantries increase due to an increased block length l. An increase of the value α leads to an increase of $f2$. To sum up, when neglecting cost the best performance can be achieved by using the smallest possible block width.

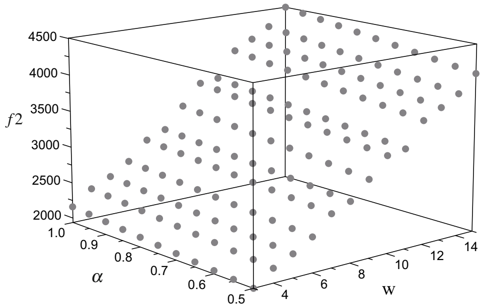

Fig. 12.10 Values of $f2$ for different values of w and α

Figure 12.11 shows the different performance improvements (for $\alpha = 0.6$) when the block width is reduced by one row, starting with a block width of 15 rows. Thus, the value of 5.6% in the column 15 → 14 in Figure 12.11 illustrates that the value of $f2$ is 5.6% lower for $w = 14$ compared to the value of $f2$ for $w = 15$. In other words, the performance improves by 5.6% when reducing the block width from

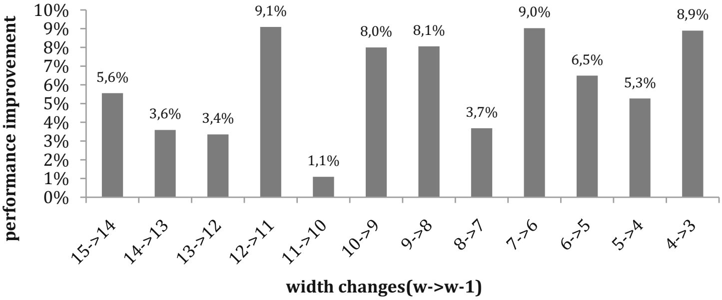

Fig. 12.11 Improvement of the performance (percentage decrease of $f2$) when reducing the block width by one row ($\alpha = 0.6$)

15 to 14 rows. As shown by Figure 12.11 the level of improvement changes for different values of w. For instance, a high improvement occurs when reducing the block width from 12 to 11 rows (9.1%). However, only a small improvement of 1.1% occurs when reducing the block width from 11 to 10 rows. Again, an explanation for this behavior is the comparatively good use of the available total yard width by the solution with 11 rows (see Table 12.3). Therefore, the reduction from 11 to 10 rows only causes a small improvement. This effect can also be seen in Figure 12.10 where the value of $f2$ just slightly increases from 10 to 11 rows.

A remaining question is how to configure the block designs when cost and performance are considered simultaneously: Having a multi-criteria problem like the BDP the aim is to find Pareto optimal solutions. These solutions are not dominated by any other possible solution. If a solution is dominated by another solution, *i.e.* the solution has higher cost and a lower performance, this solution can be ignored for planning. In the case of the BDP we can easily enumerate all solutions for a given set of parameters and check if some solutions are dominated by others. As the performance objective decreases when the block sizes are reduced, as well as the cost increase most solutions for $w = 3, \ldots, 15$ are non-dominated solutions. For $\alpha = 0.6$ and $c^c = 500$ the solutions are displayed in Figure 12.12. In this case, all solutions ($w = 3, \ldots, 15$) are non-dominated, *i.e.* each solution has either lower cost or a better performance value compared to all other solutions.

As mentioned above, a first step of planning a container terminal is to evaluate the expected seaside, yard and landside capacities (see Section 12.2.4). In addition to these values a yard performance level can be derived which, *e.g.* postulates a minimum number of moves per crane needed to handle the flow of containers of a peak scenario. Consequently, on planning a yard layout we have to consider the yard performance level. Such a performance level has to be achieved by the installed yard configuration. Otherwise congestions occur in the yard and thus the overall performance of the terminal is reduced. We assume that the defined flow of containers $F = 650$ represents a peak scenario for one hour, *i.e.* 650 containers have to be processed by all blocks in the yard during one hour. Thus, we consider the performance level as a time limit of one hour. Again, as already described in Section 12.5.1,

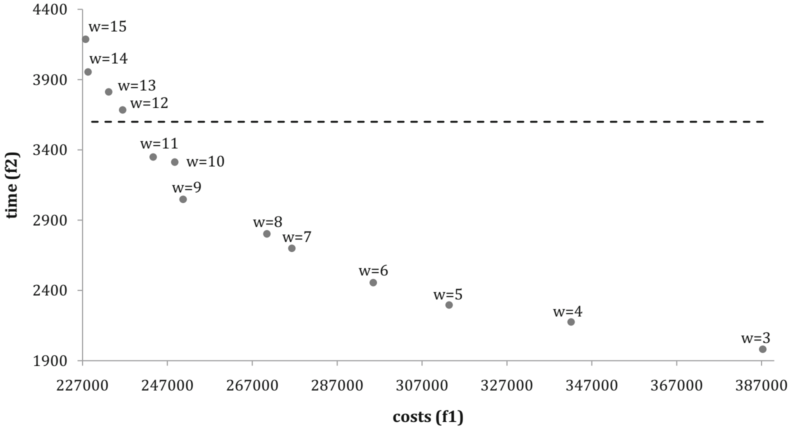

Fig. 12.12 Solutions for the BDP with a time limit $f2 \leq 3600$ seconds

exceeding the time limit by a block configuration would lower the overall terminal performance. In Figure 12.12 the dotted line represents the time limit (3600 seconds) and all solutions under the line hold the time limit. In order to find a solution of minimum cost for the BDP which achieves the needed performance, simply choose the leftmost solution that still holds the time limit. For the current example this would be the solution $w = 11$ in Figure 12.12 with $n = 22$ blocks, $f2 = 3349.6$ seconds and a used length of $l = 40$ bays. In this way a terminal planner can quickly identify promising block configurations that match the requirements of their particular scenario with respect to cost and performance.

In Section 12.2.2 we describe, besides the option of a single RMG per block, that different options with more than one crane per block exist. The BDP formulation is based on the assumption that only a single crane operates per storage block. Neglecting this assumption (and considering more than one crane per block) would not influence the fact that smaller block widths lead to a higher number of blocks and thus to a better ability to distribute the workload. A system with more than one crane per block could be an appropriate choice if for instance a high stacking capacity is needed. In this case the cycle times presented in this paper have to be adopted to a system with more than one crane. A possible way to consider a system with two cranes is to develop new estimates for the expected cycle distances of two cranes operating on a single block. Therefore, the cycle distances and probabilities in Table 12.2 (Section 12.4.1) have to be adjusted to a system with two cranes. For this purpose some rules have to be considered which control the crane operation. For instance, these rules must control which of the two cranes operates on which part of the block (*e.g.* to avoid clashing of cranes). Under consideration of these rules the cycle distances and probabilities in Table 12.2 have to be modified for a two crane system. This will result in adapted d_g^t functions which, nevertheless, still depend on the length of the blocks. These adapted functions can be used in the same manner as in this paper to find promising block designs.

12.6 Summary and Conclusion

In this paper we first briefly describe several different types of equipment and review literature which describes aspects concerning the use of equipment in container terminals. The influence of the equipment on the layout of the terminal is characterized in more detail. As a result different categories of storage yard layouts are discussed. For a specific category, a perpendicular layout using RMGs, we propose a procedure to find promising block designs. First, we analyze different distributions of the reefer racks over the storage blocks in the yard. The results show that especially in situations with high reefer rates a sufficient number of blocks should contain reefer racks, as in this case the workload can be distributed easier. Moreover, we analyze the impact of different block configurations on the yard performance and on the cost. The numerical example shows that using smaller block widths increases the terminal performance but also the cost. Due to both opposed objectives non-dominated solutions can be easily calculated. These non-dominated solutions can be used by a terminal planner to quickly determine promising block designs. The results are a first approximation of the yard performance as the proposed method does not consider, *e.g.* the influence of double cycles in which two containers are handled during one crane cycle, the influence of rehandles, and effects that occur during real-time operation. Consequently, a further step could be to use simulation to evaluate the performance of the remaining promising yard configurations more exactly.

An interesting field of further research is the evaluation of yard layout categories and their adequacy for a special situation of import, export and transshipment rates. The proposed BDP and expected cycle times for gantry movements could be adopted to configurations where twin or crossover RMGs are used.

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Chapter 13
Container Rehandling at Maritime Container Terminals

Marco Caserta, Silvia Schwarze, and Stefan Voß

Abstract
In this paper, we review recent contributions dealing with the rehandling of containers at maritime container terminals. The problems studied in the paper refer to a post-stacking situation, *i.e.* problems arising after the stacking area has already been arranged. In order to increase efficiency of loading/unloading operations, once updated information about the state of the containers as well as of the vessels becomes available, it is possible to reshuffle the container yard, or a portion of it, in such a way that future loading operations are carried out with maximal efficiency. The increase in efficiency of loading/unloading operations has a bearing on the berthing time of the vessels, which, in turn, is a widely accepted indicator of port efficiency. Three types of post-stacking problems have been identified, namely (i) the remarshalling problem, (ii) the premarshalling problem, and (iii) the relocation problem. With respect to each of these problems, a thorough explanation of the problem itself, its relevance and its connections with other container handling issues are offered. In addition, algorithmic approaches to tackle such problems are summarized.

13.1 Introduction

Container terminals can be seen as buffers within larger logistic chains encompassing worldwide distribution systems. The major purpose of using container terminals is to serve as transshipment points. Container terminals are used as temporary storage points for containers, so that, *e.g.* unloading operations from a vessel and loading operations onto a train or a truck need not be synchronized.

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Broadly speaking, a container terminal can be divided into three major areas: The quayside, *i.e.* the side in which vessels are berthed, the landside, *i.e.* the side in which other means of transportation operate (trucks, trains), and the container yard, *i.e.* the area in which containers are stored for future operations. The way in which the container yard is managed is of paramount importance in determining the efficiency of a port. Due to the fierce competition on the global market, container terminal operators are forced to increase the efficiency of their operations in order to capture and retain their customers.

As pointed out by a number of authors, *e.g.* Choe et al (2009), Park et al (2009), Stahlbock and Voß (2008), and Zhang et al (2003), some performance indicators of container terminal efficiency are: (i) the vessel berthing time, and (ii) the throughput of the quay cranes, *i.e.* the efficiency in unloading/loading containers from/to vessels. While such key performance indicators can be improved through the use of new technology, such as new equipment, terminal layout re-design, etc. the efficiency of container terminal operation can also be enhanced by *optimizing* the way in which such operations are carried out. More specifically, a great deal of attention should be devoted to the definition of efficient container stacking policies.

Moreover, in the stages of design, construction and operation of a container terminal, simulation tools play a crucial role, examples are given in, *e.g.* Gambardella et al (1998) and Yun and Choi (1999). Optimization methods, like those addressing rehandling and stacking operations at ports are suited to extend and enhance classical simulation approaches. Simulation recreates dynamical processes of real life within a (computerized) model. Experimental studies based on those models aim to gain insights on system behavior and efficient layouts of, *e.g.* manufacturing or transportation systems. Simulation has turned out to be a powerful tool for container terminal planning and its complex processes. Questions of interest are, among others, the layout of the terminal itself, including location and size of facilities (container yards, mooring, maintenance areas, etc.), design and operation of transport systems (automated guided vehicles, cranes, etc.), and modeling of container flows. Consequently, the development of simulation methods for container terminal planning has attracted research interest and respective models have been applied successfully to ports all over the world.

In terms of methodologies, several approaches like discrete-event simulation, multi-agent systems, petri-nets, or integrated simulation-optimization exist. The latter combines simulation with optimization methods by establishing the simulation tool on a higher level, having the permission to call optimization methods on a sublevel. The role of the optimization tool might differ. For instance, the optimization algorithm can take over a tactical position and be used to define and control general system parameters on an aggregate level (see Saccone and Siri (2009)). This approach is not to be mixed up with *simulation optimization* (see, *e.g.* Swisher et al (2000)) where optimization techniques are employed to fit parameters of the simulation itself *before* starting the simulation. In an alternative setting, optimization tools could be used to take decisions on a detailed, operational level. For instance, while analyzing transport systems at a container terminal using simulation, it could become necessary to call optimization tools that solve particular rehandling and stacking problems to obtain information about capacity utilization of cranes and vehicles. Along the same line, while designing a terminal layout through simulation, analysis of detailed stacking operations at container yards could become necessary to determine transport and handling times. The availability of fast optimization techniques is a crucial issue of integrated simulation-optimization tools, as typically optimization methods will be called quite often. Thus, the development of efficient optimization techniques is an important matter of terminal planning.

As highlighted in Dekker et al (2006), stacking can be seen as a three-level problem. *Strategic* stacking decisions must be made with respect to the layout of the container yard, the type of equipment, and the design itself of the container terminal. *Tactical* stacking decisions are concerned with decisions that affect capacity in the medium term, *e.g.* whether a pre-stacking area should be used, whether prearrangement policies should be implemented (remarshalling, premarshalling, etc.). Finally, *operational* stacking decisions deal with the identification of slots to be assigned to containers, the rehandling of containers within the yard, the berth allocation problem, the assignment of equipment to tasks, the definition of a loading/unloading (stowage) plan, etc. In this paper, we deal with operational stacking decisions, with a special focus on collecting previous work dealing with those operations that are carried out upon an existing stack of containers.

Let us therefore suppose that a block of the container yard has already been filled with a number of stacked containers. One of the key goals of any major port is to reduce the berthing time of vessels. Therefore, if possible, it is worthwhile to use some time before a vessel reaches the port to rearrange, or prearrange containers in such a way that the subsequent loading operations are carried out in the fastest and most efficient way possible. However, some relevant issues with respect to how to carry out these types of preliminary operations arise, *e.g.*:

- How can the loading area be rearranged with the minimum amount of crane movements?
- How can it be ensured that, during the preliminary operations of rearrangement, interference among cranes is prevented?

The focus of this paper is to provide an overview of current research on post-stacking policies, *i.e.* what could be done to prepare a stack of containers to increase the effectiveness of the future loading operations. For reasons that will become clearer later on, these policies play a vital role especially in outbound operations, *i.e.* loading of containers to a vessel. However, most of the proposed approaches could also be used to deal with inbound operations, *i.e.* loading of containers to trains or trucks.

In this paper, we use the term *stacking* to indicate the policy of container handling in which containers are piled up vertically. Typically, once containers are stacked in a pile, they can only be accessed from above, in a *L*ast *I*n *F*irst *O*ut (LIFO) fashion. Consequently, a trade-off between the effective use of the container yard surface and the minimization of container handling operations arise. On the one hand, the limited stacking area of a container yard pushes in the direction of increasing the height of the stacking area to maximize the total number of containers that can be accommodated within the yard; on the other hand, the minimization of the number of unproductive moves within the yard leads to the creation of stacks with a maximum height of one container. Therefore, the definition of a stacking policy should take into account conflicting objectives. According to Dekker et al (2006), a stacking strategy should take into account at least three objectives: (i) efficient use of storage space, (ii) efficient inbound and outbound transportation and (iii) avoidance of unproductive moves.

As pointed out by Dekker et al (2006) as well as by Taleb-Ibrahimi et al (1993), at least two different types of stacking operations can be identified: On one side of the container terminal yard, *i.e.* the quayside, *export containers* are dealt with. These are containers that arrive in the terminal in some way (*e.g.* via land) and must be loaded onto the vessel. Typically, these containers arrive somehow randomly and moreover, relevant data, like weight information, is not always given at that time. Usually, export containers arrive up to two weeks before being loaded to the vessel. However, the detailed loading sequence becomes available only shortly before the loading process. Since the stacking strategy to be used to pile up export containers can only exploit partial information, re-handling operations might be introduced to make use of information becoming available over time. On the other side of the yard, *i.e.*, the landside, containers that are unloaded from the vessel and are finally shipped via hinterland transportation are treated. These are called *import containers*. While the arrival of such containers is somehow predictable, the departure of import containers is related to the time of arrival of trucks and therefore, subject to higher variability. Consequently, using high stacking areas can lead to inefficiencies. It is worth noting though, that some authors identify a third category of containers, *i.e. transhipment containers*. These are containers that are unloaded from a vessel, temporarily stored in the yard, and loaded back to a different vessel. However, as pointed out by Kim and Park (2003), many times transshipment containers can be dealt with as if they were export containers.

A basic ingredient in the container terminal management is the *stowage plan*. A stowage plan for each ship to be loaded is defined. Such plan specifies which containers should be loaded onto the vessel and which exact position within the vessel should be occupied by each container. Factors such as containers' weight, destination, type of goods transported (*e.g.* hazardous material) are taken into account when the stowage plan is computed and released.

Whenever the stowage plan is known some time in advance, *remarshalling* operations can be performed to reduce the need for further relocation of containers. The goal of the remarshalling phase is to create stacking areas that fully take into account precedences among containers. This implies that whenever containers are to be loaded from the yard onto the vessel, the number of unproductive moves is minimum. It is worth noting though, that during the remarshalling phase containers are not retrieved and the number of containers in the stacking area is kept unchanged. The remarshalling phase is aimed at *reshuffling* containers so that in the subsequent loading or unloading phases containers can be retrieved with a minimum amount of unproductive moves.

Finally, if the configuration of a stacking area is given, regardless of whether the area is made up by import or export containers, and if containers must be retrieved following a pre-defined sequence, a *relocation* problem might arise. Whenever a container that must be retrieved first is found below containers that will be retrieved at a later time, there arises a need to relocate such containers within the stacking area in order to make the high priority container accessible. In this context, the relocation of a lower priority container is an unproductive move required to free up and retrieve a higher priority container underneath it. Therefore, while in the remarshalling phase the total number of containers in the stacking area is kept unchanged, in the relocation problem containers are retrieved one at a time, following a pre-specified order.

In this paper we assume that a *priority* is associated with each container in the stacking area, where this priority could account for a number of different factors. Some of these factors defining the priority of a container are, (i) category: *e.g.* containers with the same priority might belong to the same category and could be piled up on top of each other; (ii) departure time: *e.g.* containers with earlier departure time will have higher priority than containers with later departure time; (iii) size and weight: *e.g.* typically containers with higher weight are not stored on top of containers with lower weight, in order to respect overall ship balancing constraints.

We follow the typical terminology adopted in the context of container terminal operation. We indicate with the term *bay* a two-dimensional portion of the container yard, made up by a number of *stacks*, *i.e.* the width, and *tiers*, *i.e.* the height, as illustrated in Figure 13.1. A *block* is a set of consecutive bays, as presented in Figure 13.2. Finally, a *container yard* is made up by a set of blocks.

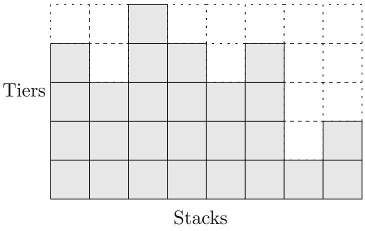

Fig. 13.1 A bay

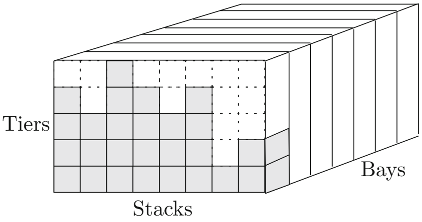

Fig. 13.2 A block

The two terms *retrieving* and *rehandling* are used to describe movement of containers. More specifically, the term *retrieving* is used to indicate a movement of a container from the bay to the vessel. Conversely, we use the term *rehandling* to indicate a move of a container within the container yard, both in the case of intra-bay or intra-block movements.

Finally, the focus of our paper is on three problems in the context of container terminal operation, namely the *B*locks *R*elocation *P*roblem (BRP), the *R*e*M*arshalling *P*roblem (RMP), *i.e.* intra-block marshalling and the *P*re*M*arshalling *P*roblem (PMP), *i.e.* intra-bay marshalling.

In all cases we consider the layout of the stacking area as given, *i.e.* the position and priority of each container in the stacking area is known. Therefore, our interest is not centered on finding effective stacking policies but rather, given a stacking area, we wish to determine how containers should be *rehandled* in order to minimize the total number of unproductive movements.

According to Choe et al (2009), Park et al (2009), and Kang et al (2006b), the unproductive movement of containers in the different phases of the container management process, *i.e.* rehandling, is perceived as the major source of inefficiency in most container terminals. Therefore, special emphasis has been put on finding approaches aimed at minimizing the total amount of rehandling needed during a vessel unloading/loading cycle. Consequently, a number of references dealing with this type of problem can be found under the captions "minimizing the number of rehandling operations," *e.g.* Caserta et al (2009a), Caserta et al (2009c), and Kim and Hong (2006) or, alternatively, "minimizing rehandling time," *e.g.* Choe et al (2009), Kang et al (2006b), Park et al (2009).

The structure of the paper is as follows: In Section 13.2 an overview of stacking approaches, *i.e.* approaches aimed at defining how containers should be piled up in the stacking area is presented. The section concludes illustrating why, no matter how well-thought the stacking policy can be, container rehandling is going to be needed during the loading phase. Therefore, Section 13.3 is devoted to the presentation of marshalling problems, aimed at reshuffling the storage area in order to eliminate or reduce the total number of future rehandling. Section 13.4 deals with a different type of problem, the blocks relocation problem. Exact and heuristic approaches for this special type of rehandling problem are presented. Section 13.5 constitutes a bridge between rehandling problems at maritime container terminals and similar problems arising in different realms. Some references to related work in other application domains are provided in this section. Finally, Section 13.6 concludes offering a brief overview of the current status in the container handling discipline along with a glimpse of future challenges and opportunities.

13.2 Container Stacking

In this section, we present a brief overview of approaches aimed at managing container terminals with respect to defining an effective stacking policy. The papers presented below study, often via *simulation*, different strategies for the container stacking problem. An overview of storage and stacking logistics at container terminals is provided in Steenken et al (2004) and Stahlbock and Voß (2008).

The stacking problem arising at container terminals is the following: Export containers of various destinations, weights, and due dates arrive at a container yard in a random fashion. Very often, not all relevant data is given at the arrival time, *e.g.* the precise weight is usually given only shortly before loading the container to the vessel. In addition, some containers need special treatment, such as containers carrying hazardous material or reefer containers. The task is to find good storage slots for incoming containers, where several objectives might be addressed, *e.g.* minimizing the number of future relocations, minimizing the overall crane utilization, or storing containers of equal destination within the same bays. The stacking problem requires optimization techniques that work with uncertain information and allow to deal with data arising in an online fashion.

Dekker et al (2006) present an interesting overview of some of the most relevant optimization problems at container terminals and propose a number of alternative policies for stacking containers in a yard. They test the validity of the proposed approaches through simulation. The simulation study concerns a time period of 15 weeks with a movement of around 175,000 containers and generates arrival and departure times for each container. Based on the stochastic set of data, a stacking algorithm made up by different stacking policies has been tested and compared against the naive random stacking policy. Total number of reshuffles, cranes workload, and level of occupation are used as performance measures of each stacking policy. The focus of the paper is on evaluating stacking strategies, *i.e.* how stacks should be filled up to achieve efficiency with respect to these performance measures. However, no details about how containers are reshuffled, *i.e.* which rules are employed, are given.

Kang et al (2006b) present a simulated annealing algorithm for the identification of stacking policies when the information about the weight of containers is not certain. The authors first explain that one of the principal reasons why rehandling occurs is due to the lack of precise information about the weight of containers. Ship balancing constraints require heavy containers to be placed at the bottom of the ship. Therefore, in order to minimize rehandling during loading operations heavy containers should always be placed on top of lighter containers when they are piled up at the container yard, so that they can easily be reversed when loaded onto the vessel. However, when the containers are brought into the terminal by trucks, only an estimate, and not a precise value of container weights is available. As a result, rehandling during the loading phase cannot be entirely avoided. The authors present a simulated annealing algorithm that allows to define an appropriate stacking policy, *i.e.* the "best" stack to be used by an incoming container is identified. A simulation approach is used: first, a random sequence of incoming containers is generated following predefined probability distribution functions that account for the likeliness of receiving containers of a given weight class. These probability distribution functions are derived from historical data. Next, a strategy to be evaluated is applied to stack the incoming containers. Once all the incoming containers have been stacked, the expected number of rehandling operations required to load these containers to a vessel is estimated. The amount of rehandling is taken as a measure of "goodness" of the stacking strategy. In order to have a more thorough evaluation, the simulation cycle is repeated over multiple runs. It is also worth pointing out that, in order to increase the accuracy of prediction of the actual container weights based upon the estimates, a machine learning approach (decision trees) to derive a classifier is employed. The authors report an improvement in accuracy when the learning mechanism is used.

Yang and Kim (2006) consider the problem of finding the stacking policy of incoming containers that minimizes the total number of rehandling operations. Each container is characterized by arrival and departure dates. When a container with early departure date is placed below another container with late departure date, a rehandling is deemed necessary. The focus of the paper is on the definition of "groups" of containers, defined as a collection of containers that can be stored together on the same stack and subsequently retrieved in any order without incurring extra rehandling. An example is given by containers with the same destination port, size and weight class. A mathematical model is proposed with the aim of creating such groups of homogeneous containers and identifying which portion of the bay should be used to stack each group. The goal of the model is, therefore, to identify the group stacking policy with minimum rehandling. Two versions of the problem are tackled by the authors: a *static* version, in which the precise information about departure date of each container is known in advance, and a *dynamic* version of the same problem, in which the retrieval date of a container becomes known only at its arrival. While in the static version of the problem the whole planned schedule can be used to find the optimal stacking policy, in the dynamic version of the stacking problem a position is assigned to a container whenever the container arrives at the yard, using updated information about the container as well as considering the current state of the bay.

Kim et al (2000) tackle the problem of determining the storage location of export containers with the aim of minimizing the expected number of future rehandling. Containers are considered one at a time, in a dynamic fashion. Whenever a new container reaches the container yard information about its weight, the current state of the bay and the distribution of the weight groups within the bay are used to assign a slot to the incoming container. An optimization model based upon dynamic programming is employed, under the strong assumption that a container is rehandled at most once. Two basic terms of the dynamic programming recursion are: (i) the probability of arrival of a container of a given weight group (estimated from historical data), and (ii) the expected number of extra rehandling generated when a container of a given group is placed at a specific slot within the current bay. Given these two terms, the dynamic programming scheme iterates over the number of available empty slots within the bay and minimizes the expected number of rehandling operations for a given set of incoming containers.

Taleb-Ibrahimi et al (1993) study the stacking problem from two different perspectives. First, they propose a set of rules aimed at determining the amount of space required to stack a set of containers without moving each container more than a prespecified number of times. Next, they study the dual problem, where the amount of space available for container stacking is kept fixed and a method to organize the storage area while minimizing the number of rehandling operations is given.

A number of authors propose "richer" approaches, in which the container handling problem is tackled from a broader perspective. These "integrated" approaches typically attempt to take into account a pool of factors affecting the total berthing time, *e.g.* traveling time of containers from the quayside to the container yard, stacking policy within the container yard, and rehandling policy.

Kozan and Preston (1999) present an integrated model that considers both the unloading and stacking problems, together. The problem is modeled as a job-shop machine scheduling problem, where the set of containers to be moved corresponds to the set of jobs to be processed and the set of available cranes corresponds to the set of machines to be used. They propose an interesting characterization of setup times. Two subproblems are identified: (i) which containers should be assigned to which crane, *i.e.* in the context of scheduling problems, this corresponds to finding which jobs should be processed on which machine; and (ii) the scheduling sequence for each crane, *i.e.* how jobs should be processed on each machine. The authors point out that, while the proposed model resembles the classical scheduling problem, a major difference consists in the way in which setup times are computed. While in the classical scheduling problem setup times are exclusively dependent on the job immediately preceding the current job, in their model the setup time, *i.e.* the time it takes to access a specific container within a stack, depends on the order of scheduling of containers initially stored on top of the target container. In this paper they propose a model aimed at minimizing the total berthing time, computed as the sum of the setup and traveling times of all containers handled. Minimizing the traveling time corresponds to finding the proper assignment of containers to cranes and minimizing the setup time corresponds to finding the optimal rehandling policy for stacked containers. The model is solved by using a genetic algorithm, where the chromosome representation captures both the container-crane assignment and the scheduling problem per crane.

In a similar fashion, Kozan and Preston (2006) present a mathematical model for the integrated problem of determining the optimal storage strategy and container handling scheduling. The main goal of the authors is to define an approach that minimizes the total throughput time, which is seen as the sum of two terms: The transferring time of the containers to the storage area and the handling time of all containers from a ship at berth. Consequently, a *container transfer model* and a *container location model* are proposed, respectively. The two separated models are finally integrated into a single model and iteratively solved using a hybrid tabu search/genetic algorithm.

Other integrated approaches are presented in *e.g.* Froyland et al (2008), Lee et al (2006), and Kozan (2000).

A different and yet somehow related problem is the one studied by Kim and Park (2003), where the problem of how to pre-allocate storage space for export containers, *i.e.* containers that are going to be loaded onto a vessel, is investigated. Such space should be allocated with the goal of maximizing efficiency of future loading operations. As pointed out by the authors, the process of determining storage locations of export containers can be decomposed into two major steps: (i) space allocation problem, and (ii) container location problem. While problem (ii) deals with the identification of the specific storage location of a container within a bay, *i.e.* stack and tier number, problem (i) only defines the amount of space and the specific area, *i.e.* how many and which bays need to be assigned to store export containers for a specific vessel. Some basic criteria are enforced in determining such area, *e.g.* bays assigned to a vessel should be located near the vessel berthing position, containers of different groups should not be mixed in the same bay etc. A mathematical model and a solution approach based upon heuristic rules are presented in the paper.

Further works dealing with the storage location assignment problem are, *e.g.* Bazzazi et al (2009), Park and Seo (2009), Han et al (2008), Zhang et al (2003), and Preston and Kozan (2001).

As pointed out by many authors, *e.g.* Park et al (2009), Kang et al (2006b), and Kim and Bae (1998), rehandling during the loading phase cannot be avoided altogether, even after a well-planned strategy aimed at identifying a stacking policy that minimizes the total number of expected rehandling is employed. Some of the reasons why this occurs are that containers to be shipped to different vessels are stored together due to the limited space capacity of the yard, the precise information about the weight of containers is not available until just before the loading operations begin and the loading plan is not yet determined when a container arrives at the yard.

13.3 Remarshalling and Premarshalling

As mentioned in the introduction, the goal of the remarshalling problem is to reshuffle containers so that no further relocations, *i.e.* unproductive moves are required when the loading/unloading phase is performed. As formalized in Choe et al (2009), "remarshalling refers to the task of relocating export containers into a proper arrangement for the purpose of increasing the efficiency of the loading operations."

Two types of marshalling activities are carried out at a typical container terminal yard: (i) intra-block *remarshalling*, in which containers that are scattered around within a block are rearranged into designated bays within the same block; (ii) intra-bay *premarshalling*, in which containers within the same bay are reshuffled. In both cases, the goal is to minimize the number of future unproductive moves.

Typically, intra-block remarshalling refers to the problem of moving a set of containers to pre-specified bays within the same block. As indicated in Kang et al (2006a), the bays in which the target containers are located before remarshalling are called *source* bays and the empty bays to which these containers should be moved are called *target* bays. Containers within a block are characterized by two types of information:

- a *group* or *category*, accounting for, *e.g.* the port of destination. In order to minimize the distance traveled by the cranes during the loading phase, containers belonging to the same group are placed in adjacent slots within the same block;
- a *priority*, accounting for, *e.g.* weight information, order of retrieval, etc. Within the same group, containers should be stacked by ensuring that no container with lower priority is found on top of a container with higher priority.

Therefore, the two-objective problem of intra-block remarshalling is aimed at grouping together containers belonging to the same category and, for each set of containers of the same category, at piling up such containers taking into account priorities.

On the other hand, intra-bay premarshalling is motivated by the use of a specific technology. As pointed out by Lee and Chao (2009) and Lee and Hsu (2007), yards that use rail mounted gantry cranes as major container handling equipment typically solve the marshalling problem at bay level. For safety reasons, in some terminals where access of containers to and from the block is usually from the side, a gantry crane is not moved from one bay to another, even within the same block, while carrying a container. Therefore, in those terminals, to move a container from one bay to another, it would be necessary to temporarily unload the container from the crane, put it on a truck, move the truck and, possibly the empty crane to the target bay, pick up the container from the truck with the crane and store the container within the target bay. This operation is time consuming and, therefore, it is avoided whenever possible. This consideration motivates the study, from a practical perspective, of the intra-bay premarshalling problem. The goal of the premarshalling problem is, therefore, to rehandle containers within the same bay in order to eliminate (or minimize) future rehandling while minimizing the total number of rehandling operations during the premarshalling process itself.

Intra-block remarshalling could be seen as more than a simple extension of intra-bay premarshalling, since more than one crane could be used to handle the containers. Therefore, typically the remarshalling problem also encompasses some considerations with respect to avoiding or minimizing interference among cranes within the same block.

Conversely, as illustrated in Figure 13.3, the premarshalling problem could be seen as a special case of the remarshalling problem, in which the following characteristics arise:

- only one source bay is given;
- only one target bay is given;
- the target bay coincides with the source bay;
- only one crane is used and, therefore, there is no need to take into account crane scheduling interference issues.

To the best of the authors knowledge, the computational complexity of the RMP has not been addressed yet. We close this gap in Section 13.4, after introducing the BRP in detail. It turns out that the RMP is NP-hard which can be proven by transforming the NP-hard BRP to the RMP.

Choe et al (2009) study the intra-block remarshalling problem where more than one crane is used to handle containers. Therefore, interference among cranes is taken into account. The problem takes as input a current configuration, in which containers are placed on source stacks and is aimed at relocating such containers into target stacks in such a way that two constraints are satisfied: (i) after remarshalling, all containers can be loaded without further rehandling; and (ii) during remarshalling, each container should be moved from its source bay to its target bay without re-

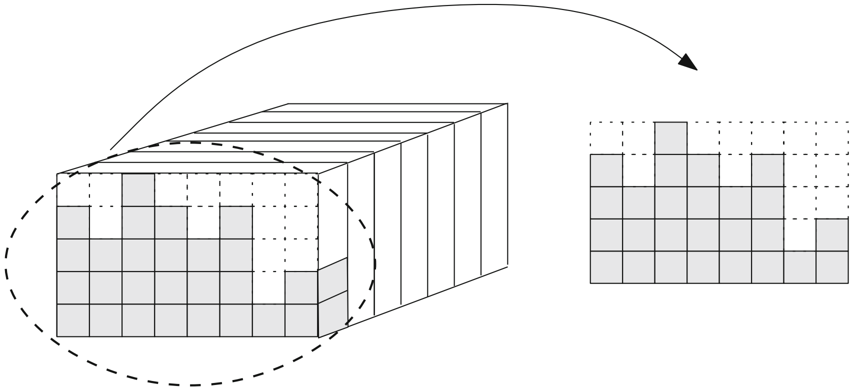

Fig. 13.3 PMP as special case of RMP.

handling. The authors propose a two-phase algorithm: The first phase is devoted to identifying the target slots to which handled containers should be moved, and the second phase is aimed at finding an optimal schedule of the cranes to actually perform the relocation of containers. The proposed algorithm, based upon simulated annealing, is aimed at finding a rehandling-free configuration of the block that can be achieved in the minimum amount of time. Based upon a partial order graph that captures all the feasible moves leading from the current block configuration to a target configuration, at each step of the search phase the algorithm evaluates the goodness of a candidate solution configuration by heuristically creating a crane schedule and estimating the time needed to complete remarshalling to achieve that particular configuration.

Park et al (2009) analyze the remarshalling problem with respect to export containers at the intra-block level, *i.e.* the reshuffling of containers is done within the same block. Typical dimensions of the considered problem are 41 bays per block, where each bay is made up by 10 stacks and 6 tiers. A block is managed by the use of two cranes, a first crane dealing with export containers and a second one dealing with import containers. Due to the large size of the considered blocks, the authors identify two sources of inefficiencies in the handling of containers. The first one is related to the horizontal movement of the cranes used to load containers to the vessel. Typically, export containers are unloaded from tracks and, therefore, are piled up near the landside of the block. This means that during the loading operations the crane operating on the waterside is forced to travel long distances toward the landside of the block to pick up export containers, hence affecting the overall time of the loading operations. A second source of inefficiency can be ascribed to the stacking of high priority containers below low priority containers, forcing a rehandling of the uppermost containers. The authors present a two-stage heuristic algorithm. The first stage uses heuristic rules to identify where, *i.e.* in which stacks containers must be relocated. Stacks are selected with the aim of avoiding future rehandling of containers during the loading operations. In the second stage of the algorithm, a cooperative co-evolutionary algorithm is used to identify the precise slot within which containers should be relocated (stack and tier), along with the order of movement of the containers to be reshuffled. Two populations are created to identify the slots and to define the order of movement. Information is exchanged in the following way: initially, a solution for the target slots identification is found; such solution is then used as input to the subproblem dealing with the movement sequence. In turn, the movement sequence defined by this last subproblem is used to find a better set of target slots and the cooperative approach is repeated in cycles.

Similarly, Kang et al (2006a) deal with the intra-block remarshalling problem, where containers are reshuffled at a block level, moving them into designated slots within the same block. As for the previous works, they deal with export containers and the objective is to find a rearrangement that avoids future rehandling during the loading operations. As in Choe et al (2009), multiple cranes are used within a block and, therefore, interference among cranes is also minimized. The problem takes as input a current configuration in which containers are placed on source stacks and is aimed at relocating such containers into target stacks in such a way that two constraints are satisfied: (i) after remarshalling, all containers can be loaded without further rehandling; and (ii) during remarshalling, each container should be moved from its source bay to its target bay without rehandling. The proposed approach is similar to the one of Choe et al (2009), since a two-phase algorithm is designed. First, a set of target locations is defined ensuring that the two main constraints are enforced. Next, a partial order graph is created with the goal of finding a set of feasible moves leading from the source configuration to the target configuration. The partial order graph captures all the possible moves leading from source to target configuration, while respecting the two aforementioned constraints. Next, simulated annealing is used to find the solution that minimizes the overall time required to carry out the remarshalling operations. Finally, a heuristic is employed to find a crane's feasible schedule. An interesting point brought out by the authors is related to the notion of neighbor solutions. Given a partial order graph, a neighbor of such graph is obtained by appropriately modifying the current one via the application of swapping among containers stored on different stacks of the same bay.

In a seminal work, Kim and Bae (1998) deal with the problem of how to efficiently move a set of containers from source bays to target bays. Containers in the target bays should be accommodated according to a pre-specified layout, called target layout. The intra-block remarshalling problem is decomposed into two subproblems: (i) the bay matching and move planning problem, in which each source bay within the block is matched with the target bay in the target layout. Decisions with respect to how many containers should be moved between any two bays are made at this stage. This part of the problem is solved using dynamic programming (to define the bay matching needs) and the transportation algorithm (to plan the movement of containers among bays and assignment to cranes). Whenever crane interferences arise throughout the container movements, the bay matching is called again under additional constraints that prohibit the conflicting bay matching; (ii) the movement sequencing problem, in which the actual movements required to reach the target layout are scheduled. Kim and Bae (1998) adopt a "macroscopic" perspective of the problem, *i.e.* only the number of containers per group type and bay are considered, whereas the actual positions and rehandling within a bay are neglected.

More recently, Lee and Hsu (2007) proposed an optimization model for the intra-bay premarshalling problem. As previously mentioned, the study of the intra-bay problem is motivated by the specific technology used at the container yard. Rail mounted gantry cranes are moved from one bay to the other while being empty, *i.e.* the trolley of the crane does not carry any container. Therefore, in order to move a container from one bay to another, even within the same block, the use of an auxiliary truck to temporarily store the container to transport it from the source bay to the destination bay is required. Such an inter-bay operation is obviously time consuming and consequently should be avoided whenever possible. For this reason, the authors study the problem of intra-bay premarshalling. The premarshalling process reshuffles the containers within a bay in order to reach a final bay layout that does not require further rehandling during the loading phase. The authors work under the following four basic assumptions:

- reshuffling takes place only within the same bay;
- containers are assumed to be of the same length;
- each crane is involved in the loading of one ship at a time;
- the loading order of containers is known.

These authors propose an integer programming model based upon a multi-commodity network flow problem. The network accounts for two dimensions, time and space. Each level of the network describes a specific point in time and captures the state of the bay at that instant. Connections between different levels of the network account for moves of containers over time and space, *i.e.* edges within the network are used to model the movement of a container from one stack to another in a given time period. The basic mathematical model, along with some extensions, is presented in the paper. Finally, in order to reduce the number of variables and to make the model tractable, some simplifications are introduced. One drawback of the model worth mentioning concerns the need to pre-define a parameter T, *i.e.* the total number of time periods required to completely reshuffle the bay. While the goal of the problem is to find the rehandling pattern that sorts out the whole bay in the minimum amount of moves, *i.e.* in the minimum amount of time periods T (which is unknown), the appropriate choice of the value of T has a strong bearing on the computational time required to solve the model. If T is chosen too large, then a very large number of variables is created and, therefore, the MIP solver might not be able to reach the optimal solution in a reasonable amount of computational time. On the other hand, if T is chosen too small, a feasible solution might not even exist. Some analysis about this trade off is presented by the authors.

Lee and Chao (2009) propose a different algorithm for the same premarshalling problem. In order to overcome the limitations imposed by the size of the integer programming model of Lee and Hsu (2007), the authors propose a heuristic approach aimed at minimizing the number of movements required to complete the premarshalling process. More specifically, a bi-objective problem is proposed: On the one hand, the authors attempt to create a reshuffled bay that requires the minimum amount of rehandling during the loading phase; on the other hand, such desired configuration should be reached in the minimum amount of steps, *i.e.* the final configuration should be reached minimizing the total number of rehandling operations. The approach is hybrid in the sense that heuristic techniques, such as neighborhood search and mathematical programming techniques, such as integer programming are intertwined to deal with different subproblems. First, the neighborhood search heuristic is used to find a chain of movements to sort out the bay in such a way that the number of further rehandling required during the loading phase is minimum. Next, a binary integer programming model is solved to reduce the number of movements required to reach that final configuration. A number of minor heuristic rules are used to foster the effectiveness of the proposed algorithm. Some comments on Lee and Chao (2009) together with a simple lower bound calculation can be found in Voß (2008).

Caserta and Voß (2009) present a metaheuristic algorithm for the premarshalling problem. The central idea of the approach relies on iteratively solving to optimality smaller portions of the original problem. The usual assumptions, *i.e.* premarshalling is carried out within the same bay, containers are assumed to be of the same size and loading preferences are known, are made. The algorithm consists of four different phases, in which ideas from the Corridor Method, roulette-wheel selection and local search techniques are intertwined to foster intensification around an incumbent solution. The algorithm is stochastic in nature and is based upon the use of a set of greedy rules that bias the behavior of the scheme toward the selection of the most appealing moves.

13.4 Relocation and Retrieval

The BRP is closely related to the previously discussed pre- and remarshalling problems but with one major difference: While pre- and remarshalling problems only consider rehandling operations, BRP also allows for retrieving operations, *e.g.* moving a container from a bay to a destination vessel. Retrieving and rehandling operations might be carried out in parallel for the BRP. Consequently, the number of containers in the bay decreases for the BRP, whereas the number of containers in the bay (block) remains constant for premarshalling (remarshalling) problems.

More precisely, the BRP is described by the following properties:

- A single bay is considered and consequently operations are carried out by a single crane.
- Containers are piled up vertically in stacks, *i.e.* only the uppermost container of each stack is accessible for rehandling or retrieving and each container is either placed on the ground or on top of another container.
- The number of stacks describes the width of the bay.
- The height of stacks is bounded by the number of tiers.
- The total number of containers in the bay is denoted by N.

- Each container in the bay is associated with a priority number, where more than one container might belong to the same priority group (indicated by the priority number). Moreover, the location of each container is given in advance.
- Containers have to be retrieved from the bay according to their priority number, *i.e.* a container with a certain priority can only be retrieved if all containers with higher priorities have already been removed.
- Containers that are to be removed next are called *target containers*. Rehandling operations become necessary, if no target container is accessible.
- A majority of models given in literature add the following condition: *(A1)* Only containers located in the same stack as and above the current target container are allowed to be rehandled (see, *e.g.* Kim and Hong (2006), Caserta et al (2009a), Caserta et al (2009c), and Caserta et al (2009b)).

The objective of the BRP is to retrieve all the containers from the bay in the prescribed order while minimizing the number of rehandling operations. As pointed out at the beginning of this section, the BRP is closely related to remarshalling. In particular, the BRP can be considered as a specific case of remarshalling as each BRP can be transformed to a remarshalling problem by the following procedure:

Transformation BRP to RMP: Given a BRP with a certain bay defined by a number of stacks and a number of tiers. Generate a remarshalling problem with a single source bay of the same size by carrying over the layout from the BRP bay to the remarshalling source bay. Moreover, generate a single and empty target bay with one stack of height equal to the number of containers to be retrieved (N) and impose the use of a single crane for carrying out the rehandling operations. A solution to the remarshalling problem with a minimum number of rehandling operations is then an optimal solution to the BRP. The transformation process is illustrated in Figure 13.4. The transformation "BRP to RMP" implies the following result:

Lemma 1 *The remarshalling problem is* NP*-hard.*

Proof 1 *Assume there exists a polynomial algorithm for RMP. Then each BRP instance could be solved in polynomial time as a polynomial transformation from BRP to RMP exists. However, BRP is proven to be* NP*-hard (Caserta et al (2009b)) and, unless* $\mathsf{P} = \mathsf{NP}$ *holds true, there is no such polynomial algorithm.*

So far, only a few publications have discussed the BRP. Kim and Hong (2006) describe the BRP together with assumption *(A1)* and suggest two solution procedures. First, in an exact approach a branch-and-bound method is described that branches over all possible bay layouts resulting from the retrieval of a target container. For determining lower bounds, the *confirmed rehandlings* are counted and added to the already realized rehandling, where each container located above a container with higher priority causes a confirmed rehandling. Second, Kim and Hong (2006) proposes a heuristic method based on the *E*xpected *N*umber of *A*dditional *R*ehandling (ENAR). Each time, if there is more than one rehandling operation possible, choose

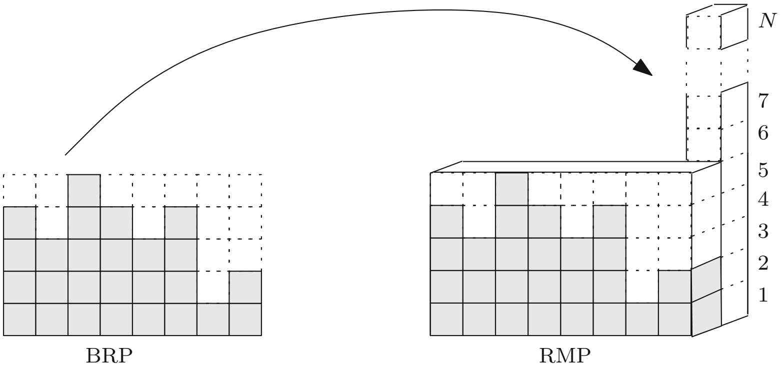

Fig. 13.4 Transformation BRP to RMP

the one that minimizes the ENAR for the resulting bay configuration. Experimental studies are carried out for scenarios where precedence relations are given among individual containers, *i.e.* each priority group has exactly one member and for scenarios where precedence relations are given for container groups. The exact branch-and-bound approach is compared with the heuristic method and an average increase of the number of rehandling operations up to 7.3 % is reported for using the heuristic instead of the exact method.

Caserta et al (2009a) describe a novel encoding of the bay to a binary matrix and describe the benefit of this encoding in terms of computational matters. Fast access to information about the current layout of the bay is enabled and fast transformation of bays when rehandling takes place is possible which, in turn allows a lean and fast implementation of the solution method. The BRP as well as the pre-marshalling problem are stated in the notion of the binary encoding. Nevertheless, the focus of the article is on investigating the BRP under assumption *(A1)*. In particular, a random-guided look-ahead procedure is implemented. This metaheuristic approach is based on a set of simple rules that are used to compute heuristic solutions based on any initial bay configuration. The objective function value of these heuristic solutions serves as a score for the quality of a found partial solution and as an upper bound for the search procedure. The experimental study compares the results of the presented procedure against those of Kim and Hong (2006) and Caserta et al (2009c) and proves the quality of the proposed method by showing a decreased average number of rehandling operations in the solution.

Caserta et al (2009c) present a corridor method algorithm for the blocks relocation problem, in which a dynamic programming scheme is presented and used in a metaheuristic fashion. The approach belongs to the realm of hybrid algorithms, since mathematical programming techniques are used within a metaheuristic framework, iteratively solving to optimality “constrained” versions of the original BRP.

To the best of our knowledge, Caserta et al (2009b) is up to now the only work presenting mathematical model descriptions for the BRP. Two mathematical formulations are proposed, where the first one (BRP-I) is not taking into account condition

(A1), whereas the second one (BRP-II) does. Thus, BRP-I is exploring a larger solution space and an example showing that BRP-I is indeed able to find better solutions than BRP-II is presented. On the other hand, assumption *(A1)* allows a leaner formulation which results in shorter computational times for solving the problem using a commercial MIP-solver. Consequently, using BRP-II, larger instances can be addressed compared with BRP-I, as reported in the computational study. In addition, in the same work, upper bounds on the number of rehandling operations are presented. Furthermore, the complexity of the BRP is stated as NP-hard for the BRP, as well as for the BRP under assumption *(A1)*. Finally, a simple heuristic rule is proposed and measured against the exact solution and the heuristic solution of Kim and Hong (2006).

13.5 Related Work in Different Fields

Stacking, sorting and rehandling problems are discussed not only in the context of containers and ports, but also in different areas like warehousing, production planning, and artificial intelligence. This section is not meant to give a comprehensive overview of the work in different fields, but to refer the interested reader to related notions and concepts.

Some warehouses are organized following the stacking principle by storing uniform items piled up on top of each other, where access is only granted for the uppermost item. Stacking operations in those warehouses follow similar rules as in container yards. However, a major difference between container yards and warehouses is given by the item flow, as warehouses have to offer retrieving and receiving operations in parallel (see, *e.g.* Nishi and Konishi (2009)), whereas in container yards the receiving operations are usually completed before the retrieval operations take place. Moreover, in general warehouses handle a much larger number of items than container yards. In addition, the physical properties of the items in a warehouse might differ from those of a box-shaped container. For instance, in the steel industry coils are stored by stacking them on top of each other. The resulting storage setting is not forming "stand-alone" stacks, as each coil is placed on top of two consecutive coils from the row below (see, *e.g.* Zäpfel and Wasner (2006)).

Also the handling of trains involves stacking operations; see, *e.g.* Felsner and Pergel (2008). A train can be seen as a sequence of wagons. It might happen that the wagon sequence of a single train needs to be changed or that the wagons of several trains have to be *reshuffled* to new collections of trains. These operations are physically carried out on dead end sidings, where trains or part of trains can be stored intermediately and taken away later on. Thus on dead end sidings trains can be "stacked" together and moreover, rehandling of wagons is possible. Each of those dead end sidings relates to a stack in the container yard, where only the uppermost container/wagon is accessible.

A well-known concept in artificial intelligence is that of blocks-world (see, *e.g.* Romero and Alquézar (2004), Gupta and Nau (1992)). The blocks-world is carried out on a “table” where blocks are stacked on top of each other. A typical blocks-world instance consists of a given initial table state and a desired goal state. The task is to transform the initial state to the goal state with a minimum number of moves. Variants of blocks-world incorporate limitations on the table size and different levels of given conditions for the goal state. Gupta and Nau (1992) prove the NP-hardness of blocks-world and Caserta et al (2009b) show that the BRP is a particular case of blocks-world.

13.6 Conclusion and Future Challenges

Ever since the first containers were introduced in the early 1960s, container handling techniques and strategies have always been key factors in measuring the efficiency of major ports. However, due to the growth of container vessels in recent years, whenever one of such ships berths at a port, a number of containers that would have been unthinkable some time ago must be handled in just a few hours. This poses a serious challenge for container terminal operators, since the volume of traffic has grown exponentially while the available surface for managing such traffic has remained virtually unchanged. Therefore, optimization techniques for handling and rehandling containers acquire a prominent role in fostering efficiency of container terminal operation.

In this paper we have presented a survey of techniques for post-stacking situations, *i.e.* once the stacking area has already been filled with containers. Exploiting the fact that updated information becomes available while the vessel approaches the port, export containers could be rearranged prior to the arrival of the vessel with the objective of minimizing the time required for future loading operations. We have identified three classes of post-stacking problems:

- the *remarshalling* problem, *i.e.* the problem in which one wants to rehandle containers from a set of source bays to a set of target bays within the same block. Such containers are rehandled in such a way that future loading operations will be carried out with the maximum efficiency;
- the *premarshalling* problem, *i.e.* the problem in which one wants to reshuffle containers within the same bay. The crane used to carry out these operations is kept fixed over the specific bay and, therefore, no horizontal movements of the crane are allowed. As in the previous problem, the final layout of the bay is such that the number of future relocations required to load the containers is minimized, or eliminated altogether;
- the *relocation* problem, *i.e.* the problem in which one wants to retrieve containers following a prescribed list of precedences among containers. Such retrieval operations are carried out minimizing the total number of rehandling operations.

Some of the challenges concerning the aforementioned problems from the operations research point of view are, *e.g.* the design of efficient algorithms for online optimization, the use of recent findings in the metaheuristic field and the development of broader, integrated approaches for container terminal logistics.

With respect to the design of algorithms for online optimization, as presented in this paper, a number of heuristic rules have been proposed for any of these problems. However, a more thorough effort with respect to the design of learning mechanisms inspired by metaheuristics could be made, in a fashion similar to what is proposed by Bazzazi et al (2009), Lee and Chao (2009) and Kozan and Preston (1999). Perhaps one of the major challenges facing operations research experts in designing metaheuristic algorithms consists in proposing alternative encodings for such problems. The dynamic nature of the problem itself seems to impose a "constraint" in the type of encoding used. However, ideas about alternative encoding schemes for any of these problems could lead to the design of radically different approaches. As it often happens with metaheuristic algorithms, such approaches should be fast enough to be used in dealing with online optimization.

When it comes to exploring recent findings in the metaheuristic field, one of the new trends concerns connecting metaheuristic paradigms with classical mathematical programming techniques. In general, such mathematical programming techniques are used in a metaheuristic "philosophy," in the sense that the powerful exact technique is exploited only on a limited portion of the solution space, or perhaps over different portions of the solution space, as opposed to attempting to solving the original problem to optimality. This could lead to more powerful algorithms that could produce higher quality solutions. Some ideas about how to use mathematical programming techniques in the spirit of metaheuristics are provided in Maniezzo et al (2009). Similarly, a first application of such approach in the context of the blocks relocation problem has been proposed in Caserta et al (2009c).

Finally, a third avenue of opportunity could be offered by recent advances in computer technology and parallel computing. Due to the astonishing increase in computational power, problems that in the past were seen as intractable, today can be dealt with using, *e.g.* parallel or grid computing. The interesting aspect is that broader models, perhaps taking into account more than one single optimization problem at a time, can now be considered and solved. The current trend so far has been the one of "divide and conquer," *i.e.* to take the original logistic problem and to divide it into smaller problems. Each one of these smaller problems is then solved, either heuristically or exactly. However, due to this spur in computing power, perhaps it is now possible to tackle larger problems taking into account a bigger portion of the whole picture. This idea is in line with what is attempted by, *e.g.* Kozan and Preston (1999), Kozan and Preston (2006), and Lee et al (2006).

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Chapter 14
RMG Crane Scheduling and Stacking
Overview and Implications on Terminal Planning

Nils Kemme

Abstract
The container yard plays as major role in the competitiveness of container terminals. The latest trends in container yard operation are different kinds of automated rail-mounted gantry crane systems. Within the scope of modern terminal planning, these systems are of great relevance, but the strategical planning decisions are generally based on simplified assumptions about the capabilities of automated rail-mounted gantry crane control, *i.e.* the methods used for solving container stacking and yard crane scheduling problems. Planning decisions for the whole terminal depend on the effectiveness of operational planning procedures considered for rail-mounted gantry storage automation. First, an extensive overview on scheduling and stacking approaches is given. Secondly, the effects of different scheduling and stacking approaches on terminal planning decisions are explained.

14.1 Introduction

Over the last decades, the world trade, especially between Asia and Europe as well as between Asia and the U.S., has continuously increased, and in spite of the current economic crisis this trend is expected to continue in the long term (see Min et al (2009)). As a consequence thereof, the volume of seagoing container traffic has increased even faster, often with double-digit growth rates. Looking for economies of scale, *i.e.* reduced costs per container shipped, shipping lines decided to expand their fleet by ordering ever-increasing vessels and the end of this trend cannot be foreseen yet.

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As a consequence, shipping lines tend to make fewer but longer calls with their big vessels, *i.e.* the number of containers to be unloaded and loaded in each port on the route of a vessel (moves per call) is expected to increase. As no container is transported while a vessel berths in port, the shipping lines want the in-port time of their large vessels to be as short as possible. Hence, container terminals are faced with demands of the shipping lines for higher quality and performance concerning their loading and unloading processes. Therefore, the cost and time efficiency of terminal operation are important factors for the competitiveness of related facilities. Along with the ever increasing container volume and the increased moves per call, more and more storage capacity is required in the ports. Consequently, port area has become a scarce resource in international container ports, especially in Asia and Europe.

Nowadays, port area and processing time to turn around a vessel are major bottlenecks at container terminals. While the required port area obviously depends on the dimensions of the storage yard, researchers and operators have traditionally focused on ship operations when optimizing the turn around time of vessels. But since longer and highly unpredictable times needed to store a container in or retrieve a container from the storage area directly lead to interruptions of the quay cranes' unloading and especially loading processes, the storage yard also plays a vital role in the turn around times of vessels. Moreover, the container yard is not just the storage area for containers; it is the interface between waterside and landside transport chains. Most of the terminal operations either originate from or cease at the container yard.

The major trend in stacking equipment is the usage of gantry cranes. Two systems have to be distinguished, namely the *R*ubber-*T*yred *G*antry crane system (RTG) and the *R*ail-*M*ounted *G*antry crane system (RMG). Several authors evaluate the performance of these systems by comparison (see, *e.g.* Saanen et al (2003), Chu and Huang (2005) and Vis (2006)). Compared to *S*traddle *C*arrier (SC) stacking, the crane systems offer significantly denser stacking along with still acceptable storage and retrieval times. One of the major advantages of RMG systems – especially for high-labor-cost countries – is their proven potential for automation. A group of authors compare the performance differences of various types of RMG systems (see, *e.g.* Valkengoed (2004), Saanen and Valkengoed (2005) and Saanen (2007)). Besides these strategically oriented system comparison studies there is only little RMG related literature available that deals with operational problems. Only a few papers are focused on stacking and scheduling, which can be regarded as the most essential operational planning problems for RMG systems. Within container stacking, the question of where to store an incoming container has to be answered. RMG crane scheduling deals with the problem of dispatching and sequencing storage and retrieval requests, *i.e.* which gantry crane executes which request and in which order.

Within the scope of this work, a critical overview of stacking and scheduling in the framework of RMG terminals is given. Thereby strategies and methods that are already known as well as modified and new approaches are discussed and evaluated in terms of their applicability for RMG yards. In addition, the implications of these operational planning problems on strategical terminal planning are explained. In Section 14.2 a description of storage logistics within RMG crane systems is provided. Section 14.3 is dedicated to stacking policies for RMG terminals. Afterwards, in Section 14.4, scheduling policies for RMG cranes are discussed. In Section 14.5 the importance of these stacking and scheduling policies for strategical terminal planning is discussed. Finally, a summary and conclusions are given in Section 14.6.

14.2 Storage Logistics with RMG Cranes

The usage of RMG cranes within container yards is one of the latest trends in container storage logistics. Since the beginning of the 21st century, various types of RMG crane systems have been implemented in container terminals around the world (see Saanen (2004)). Within this section, these systems and their effects on the storage operation are shortly explained. Furthermore, some basic information on the planning conditions for the container stacking and crane scheduling problem are given: The major input for the stacking problem – the stowage plan – as well as the consequences of the uncertain planning situation are explained.

14.2.1 RMG Crane Systems and Operations

Container terminals that make use of RMG cranes for stacking operations are usually organized in the form of several parallel yard blocks which can be arranged parallel or perpendicularly to the quay wall. This paper focuses on the most common RMG yard being laid out perpendicularly to the quay wall with handover positions only at the waterside and landside ends of the blocks. Due to clear separation of internal and external traffic the layout offers high potential for automation of RMG cranes as well as the horizontal container transport between quay and yard cranes. The latter is usually done by *A*utomated *G*uided *V*ehicles (AGV) or straddle carriers. The layout of an exemplary RMG container terminal, that is referred to here, is shown in Figure 14.1.

Nowadays, four different RMG systems are known for the perpendicular block layout, which are all illustrated in Figure 14.1. They are quite similar in terms of container flow and at first glance mainly differ in the number of cranes used per block. The *single* crane system is the oldest RMG crane system and was introduced in Rotterdam, Netherlands in the 1990s (see Saanen (2006)). Each block is operated by a single RMG crane, which serves landside and waterside handover positions. The major advantage of the *single* system is its comparably simple behavior, which simplifies the crane scheduling problem. But the handling capacity of just one crane is rather small, therefore the system can result in long waiting times for external trucks and disturbed supply chains of the quay cranes.

A consequent derivative is the usage of two identical yard cranes per block. As the cranes have the same size and share tracks, passing of cranes within the same block is impossible. Consequently, one crane serves the waterside handover posi-

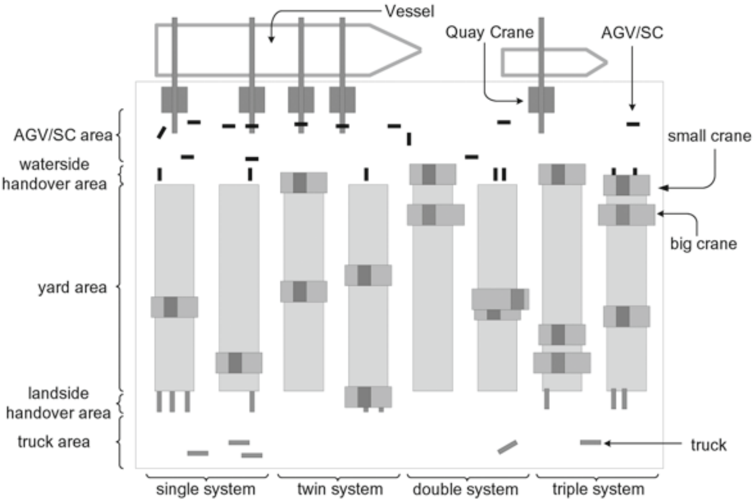

Fig. 14.1 RMG Terminal layout with different crane systems

tions and the other one the landside handover positions. Subsequently, this system is referred to as *twin*. On the one hand, it is beneficial that the system offers an increased handling capacity compared to the *single* one, but on the other hand, it is more complex to operate, since crane interferences have to be considered. In addition, the system is very vulnerable to machine breakdowns, since crossing of the cranes is not possible and thus a defective crane may jam the whole yard block. A *twin* system is for example in operation in Portsmouth, Virginia (see Edmonson (2007)).

A comparable handling capacity along with a higher degree of flexibility can be reached by the *double* crane system, which also uses two cranes per block but allows for crossing. Hence, each handover position can be served by both cranes. This can be facilitated by using two cranes of different sizes which do not share tracks but have their own pair of rails each. However, crossing is only possible if the trolley of the bigger crane is moved to a special crossing position which is located at the side of the big crane, beyond the profile of the small crane. The crossing lane of the big crane, which is illustrated in Figure 14.2, is not used for container storage, but for M&R-purposes. Such a system is in operation in Hamburg, Germany (see Saanen (2006)). The benefits of the crossing possibility are reduced (but nevertheless existing) crane interferences and reduced consequences of machine breakdowns. The downside is a higher area requirement per block, due to the second track and the crossing lane. Thus fewer blocks can be installed in a given yard area.

The latest development of automated RMG systems is the *triple* crane system. It has recently been put into operation in Hamburg, Germany (see Anonymous (2008)). Three cranes will be used per block: Two identical cranes sharing the same tracks and one bigger crane with its own rails. While – comparable to a *twin* system – the two small cranes cannot pass each other, the bigger one can pass both small ones, which is comparable to a *double* system. On the one hand, deploying three cranes per block increases the handling capacity, on the other hand, more crane interferences have to be considered which makes scheduling even more complicated than for the *twin* and *double* systems.

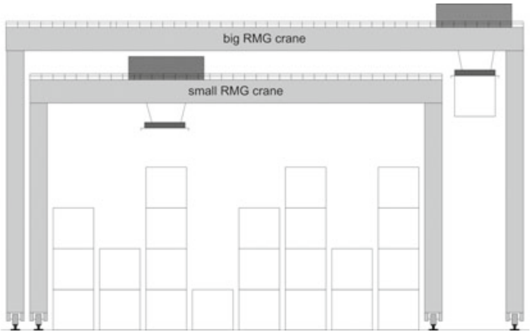

Fig. 14.2 Profile of an automated RMG crane system with crossing ability

14.2.2 Stowage Plan

The loading sequence of a container vessel is always based on a stowage plan which defines the exact storage position for containers to be loaded. Usually, the stowage plan is made in two subsequent steps. First the shipping line creates a rough plan, which only contains the total number of containers to be loaded and the reserved slots within the vessel for each port of destination. The second step is carried out by the ship planners of the terminal just a few days before the arrival of the vessel. The rough plan made by the shipping line is filled with actual containers. The objective of the stowage plan is to minimize the number of shuffle moves during the route of a vessel with respect to guaranteeing the ship's stability. From the latter it follows that heavier containers have to be stacked underneath lighter ones. Shuffle moves in the following ports may occur, if containers designated for that port are stacked below containers that will be unloaded in subsequent ports. As shuffle moves reduce the quay crane productivity and by this increase the in-port-time of vessels, shuffle moves should be avoided. Thus, containers with the same destination should be stacked on top of each other. In addition, the stowage plan has to be created subject to required special locations for containers carrying dangerous goods or reefer containers. The stowage plan creation is supported by sophisticated software tools, which usually apply offline stowage planning. Thereby the exact loading sequence of containers is fixed in advance for each vessel. In contrast, online planning offers the potential to change containers with the same attributes during the loading process whenever appropriate. Thus, the stowage plan can flexibly be adjusted to stochastic influences like machine breakdowns or drops in performance.

The stowage plan and the underlying planning principles are of great importance for the stacking of export containers in the yard, since the containers have to be retrieved from the stack in the sequence of the stowage plan. Therefore, shuffle moves in the container yard can be avoided by stacking the containers with respect to the stowage plan. However, as the concrete stowage is often unknown until a few days or even hours before the arrival of the vessel, stacking all containers according to the stowage plan is impossible. Hence, a good stacking policy can only anticipate the future stowage plan as well as possible.

14.2.3 Online Situation

In classic optimization, which is termed offline optimization here, it is assumed that all input data of an instance is known before applying solution methods. However, for many applications this assumption is not realistic, as decisions have to be made based on incomplete or uncertain information. As a consequence, it may be necessary to compute several partial solutions of the overall problem whenever new data of the problem become available. Within the scientific literature, such planning situations are denoted as online. An algorithm runs online if decisions are made whenever a new piece of data demands an action (see Fiat and Woeginger (1998)). Furthermore, real world applications often require the online algorithms to respond very fast, *i.e.* new decisions, which are induced by a new piece of data, have to be computed within very tight time frames. In this case, the algorithm also has to meet real-time requirements (see Ascheuer et al (1998)).

Due to the computing of solutions piece by piece by the online algorithm, some parts of the solution will be computed which will turn out to be suboptimal after the complete data set is available. Hence, the solution quality of online algorithms cannot be expected to be as good as that of omniscient offline algorithms. However, special online algorithms have to be applied, which respect the feature of only stepwise available data. Independently of the actual planning problem, the following concepts can be distinguished for the general design of online algorithms (see Grötschel et al (2001)):

*F*irst-*I*n-*F*irst-*O*ut (FIFO):

The *FIFO* strategy strictly serves requests in order of appearance. Efficiency issues are not considered.

Greedy:

A *greedy* algorithm serves that request (next) which leads to the least costs with respect to the current system state and the corresponding objective, *i.e.* the algorithm acts greedily.

Replan:

The *replan* strategy computes an optimal solution at a specific point in time. Every time some new piece of data is available, a new optimal solution is computed. All schedules made beforehand are replanned.

Ignore:

The *ignore* strategy also computes optimal solutions at a specific point in time, but the schedule made is executed and not replanned. When the current schedule is finished, a new one is computed for the new requests which may have become available in the meantime.

The concept of online optimization is of great importance to the field of container terminals, since many planning problems on the operational and real-time level have to be regarded as online situations. For internal and external reasons, the daily terminal operation is characterized by imperfect and uncertain information. To a large extent, the operation is dependent on external processes like the arrival of vessels, trucks and trains, which are not very predictable. Besides these external processes, the internal operation is also uncertain to some degree since machine breakdowns can occur and the performance of manually controlled processes is in general subject to variability. Until today, just a few authors have directly focused on terminal planning problems from the perspective of online optimization (see, *e.g.* Steenken et al (2001), Grunow et al (2004) and Grunow et al (2006)).

Likewise, container stacking and yard crane scheduling have to be regarded as online problems, since the arrival times and sequences of related transport machines at the handover positions of the yard blocks are highly uncertain or even unknown. At the landside interface of the stacking yard, an arriving truck is completely unknown before passing the gate of the terminal, unless a preregistration system is used which assigns time slots for the processing of certain trucks. The container flow at the waterside ends of the yard blocks is somewhat more predictable because the information quality is substantially better regarding the expected time windows of in- and outbound movements. This enables more sound control decisions, especially in the field of container stacking. Furthermore, the quay crane loading and unloading processes, as well as the transport to the RMG blocks are controlled by the terminal operator. However, the look-ahead horizon for container arrivals at the waterside handover positions of RMG storage blocks is short. Only the arrivals within the next few minutes can be qualified as predictable, because until the internal transport vehicle has started its drive to the block, a lot of disturbances are still possible. In summary, container stacking and yard crane scheduling are highly dependent on the preceding processes and thus online optimization is the method of choice.

14.3 The Container Stacking Problem for RMG Container Yards

The container stacking problem deals with the question where to place incoming containers in the yard area. Nowadays, this planning problem is not that easily solved, since several conflicting objectives and constraints have to be considered. An increasing stacking height, a declining accessibility and an increasing demand for on-time retrieval processes lead to more elaborate problems. Within this section, first the objectives and constraints of container stacking are explained. Subsequently, a literature overview on related solution strategies and methods is given. Finally, these stacking methods and strategies are classified and evaluated.

14.3.1 Problem Description

Depending on the location of container terminals, the area available for container stacking often is a scarce resource. Especially for terminals located in grown industrial port structures, the amount of area available is not unlimited when it comes to terminal expansion plans. Therefore, terminal operators are usually seeking for efficient usage of the available storage area, *i.e.* a high storage capacity should be realized per available storage space. Hence, terminal operators tend to increase the stacking height, if storage space is a scarce resource. In addition, the storage yard indirectly affects the quay crane performance, which is often regarded as the most important performance indicator. The quay cranes and the storage yard are connected by the waterside horizontal transport modes. An efficient use of this transport equipment, as well as a timely accurate container flow to and from the quay cranes is facilitated by fast and punctual storage and retrieval processes of the container yard. Besides the efficient use of yard crane resources, which is controlled by the used crane scheduling method, this objective depends on the number of required shuffle moves. By avoiding stacking of containers on top of containers that have to be retrieved before the others, a stacking procedure can minimize the number of unproductive shuffle moves. Hence, two major stacking objectives – maximizing the number of containers stored per yard space and minimizing the number of shuffle moves – are identified. But since high and dense stacking generally leads to more shuffle moves (see, *e.g.* De Castilho and Daganzo (1993) and Kim et al (2008)), these are conflicting objectives. However, this trade-off can be mitigated by stacking approaches which take advantage of the available information for each container.

Accurate data on container departure times is the most crucial information that is needed in order to avoid shuffle moves. Usually this information is not directly given, but can only be anticipated from the other characteristics of the containers. However, availability and accuracy of container data is greatly dependent on the corresponding flow direction. Import containers arrive in large container vessels and continue towards their destination through hinterland transport. While the arrival of import containers is to some extent predictable, the departure can be regarded as absolutely unpredictable, since the arrival time of external trucks is generally not announced in advance and additionally depends on external events like traffic jams. For export containers, the situation is reversed. While the arrival via hinterland transport is somewhat random, their departure is usually more predictable, as it is connected with a vessel. Subsuming, waterside processes are more predictable than hinterland processes. Since the outflow is more important for container stacking, waterside outgoing containers, *i.e.* export as well as so-called transshipment boxes, are therefore more suitable for the application of elaborate stacking approaches. Besides the flow direction, information on the type, size, weight, departing mode and destination of the container may be available.

14.3.2 Literature Overview

Relevant stacking literature for all kinds of stacking systems can be found in the literature overviews of Meersmans and Dekker (2001), Vis and Koster (2003) and Stahlbock and Voß (2008). Several authors have published papers on container stacking, but most of them are directed on stacking problems for RTG systems. Despite this great attention for RTG crane systems, the proposed strategies and methods are often not appropriate for RMG systems, since the logistic operations differ a lot.

While an RMG system (as it is regarded here) only serves the vehicles for horizontal transport at the ends of the yard blocks, within an RTG system loading and unloading of trucks is done adjacent to the whole block. Consequently, each storage or retrieval move in RMG systems begins or terminates at the block ends and thus long bay-wise crane travel-distances are an integral part of this storage system. Due to technical restrictions, RTG cranes generally do not traverse bay-wise when charged with containers. They only move containers within the same bay, *i.e.* a container is picked up from a truck in the handover lane in parallel with the current bay of the crane and moved to a dedicated slot of that bay by a trolley move. This is also important for shuffle moves, as relocating is only possible within the same bay. After finishing work within one bay, the RTG crane traverses to the next bay. Therefore, minimizing crane traversing alongside the block is often regarded as major objective for RTG crane systems and it is tried to bundle the execution of storage and retrieval jobs in the same bay. Consequently, many authors treat stacking and crane scheduling as combined problems for RTG systems (see, *e.g.* Kim and Bae (1998), Kim et al (2000), Hirashima et al (2006), Kang et al (2006b), Kang et al (2006a), Kim and Hong (2006) and Aydin (2007)). Therefore, most literature on RTG stacking is not applicable to RMG systems. However, the common stacking objective of RMG and RTG systems is the minimization of shuffle moves, hence general stacking strategies avoiding shuffle move are useful for both systems.

The literature overview by Steenken et al (2004) contains a description of generally applicable stacking strategies, which are used in practical terminal operation. They distinguish the strategies of *remarshalling stacking*, *reservation stacking* and *scattered stacking*. The *remarshalling stacking* works as follows: After a new export container has been received by the terminal, it is stored in a temporary storage area without consideration of its load attributes. Next, a stowage plan for the vessel is made. At a predefined time, before the arrival of the respective vessel (*e.g.* 24 hours), the export containers are retrieved from the temporary storage area and brought to the *premarshalling area*, where they are stacked according to the stowage plan, *i.e.* in a way so that shuffle moves are minimized. After the arrival of the loading vessel, the containers are retrieved from the *premarshalling area* and loaded onto the vessel.

Within the framework of *reservation stacking*, storage areas are allocated in advance to the arrival of a vessel according to the expected number of import and export containers, *i.e.* specific storage locations are reserved for unspecific dummy containers. Hence, a specified number of storage positions are blocked for other storage activities far in advance of the actual arrival time of that vessel. Thus, the storage capacity is virtually, but not physically, reduced.

In contrast, *scattered stacking* does not assign yard areas and storage capacities in advance to a vessel's arrival. Moreover, the yard areas are uniquely allocated to a specific berth. For each calling vessel, export containers are then stored in the dedicated storage area for the used berth. On the arrival of a vessel, a location for each container to be unloaded will then be searched in real time within the dedicated storage area. All export containers arriving beforehand also have to be stored in the specified storage area.

Chen (1999) examines stacking strategies for various types of container yard systems which can also be applied to RMG stacking. He differentiates between export and import storage management, as the information on the *E*stimated *T*ime of *D*eparture (ETD) of the containers differ a lot (see Section 14.3.1). Therefore, import and export boxes should not be intermingled. Two major stacking strategies for export containers are identified – namely *premarshalling* and *sort and store*.

While *premarshalling* is comparable to the *remarshalling stacking* explained above, arriving export containers are stacked according to the following container attributes by the *sort and store* strategy:

1. Shipping line: *e.g.* boxes of Hapag Lloyd and Maersk should not be mingled when stacked.
2. Loading vessel: Boxes designated for different ships should not be mingled when stacked.
3. Discharge port: Boxes destined for Port A should not be mixed with those for port B.
4. Container type: 20 ft and 40 ft as well as special containers should not be stacked together.
5. Weight category: For reasons of stability heavy containers are usually stored below lighter ones on the vessel. Therefore, export containers are categorized in a defined number of weight classes. Containers of different weight classes should not be stacked in mixed piles.

After the arrival of the loading vessel, the containers are retrieved from the storage area and loaded onto the ship. For import containers, there are no such straightforward stacking strategies as for export containers, since only unreliable or even no information on the ETD is available. Consequently, Chen (1999) recommends a lower stacking height for import containers compared to that of export containers, because higher stacking inevitably leads to more shuffle moves and a reduced productivity.

A simulation study on stacking methods for an automated *single* RMG system with 27 blocks, each 40 long, 6 wide and 3 high is carried out by Dekker et al (2006). The horizontal transport at the waterside is done by AGVs. Simplifying, the crane capacities are not realistically mapped and the average occupation rate of the container yard has been set to only 50% of the physical capacity. A block-wise distinction between import and export boxes is not assumed. Two methods – namely *random stacking* and *category stacking* – and several enhancing features for these methods have been tested by Dekker et al (2006).

Within the framework of *random stacking*, a storage position is randomly generated. The position is accepted whenever the position is a ground position or when it is on top of a same sized container (20 ft/40 ft). Otherwise, a new position is randomly generated until an acceptable one is found. This method can be denoted as a benchmark method for more sophisticated methods.

Category stacking as applied by Dekker et al (2006) is based on the idea of *sort and store stacking*. They assume online stowage planning is applied and therefore export containers of the same category are exchangeable during the loading process. Consequently, shuffle moves can be reduced compared to a fixed loading sequence. Whenever a new container has to be stored in a block, all empty piles as well as piles of the same category that are not completely filled are determined and out of these possible piles, a storage location is randomly chosen. In case no possible pile is available, the next block is searched for a possible pile and finally, *random stacking* is applied.

Besides these two methods, Dekker et al (2006) investigate several extensions and modifications. A preference for ground locations is introduced to reduce high stacking. Within a further modification, containers are to be positioned close to the departure handover position to reduce the retrieval times. Additionally, the number of possible locations can be extended by allowing containers to be stacked on top of other containers which are expected to depart later. Thereby the number of possible storage locations can be increased without causing more shuffle moves.

Besides the papers presented by Dekker et al (2006), Chen (1999) and Steenken et al (2004), further applicable publications for stacking within RMG operated container yards are not known at present. To the best of the author's knowledge, for multi-crane RMG systems, *i.e. twin*, *double* and *triple* crane systems, no stacking-related literature has been published yet. In the next subsection, the stacking strategies and methods explained so far are discussed and judged regarding their application for RMG systems. Thereby, a classification of stacking approaches is given and useful enhancements for multi-crane systems are suggested.

14.3.3 Classification and Evaluation

According to the preceding literature overview, the positioning of an incoming container depends on the flow direction of the container (import, export) as well as the terminal's decisions on the subdivision of the yard area (*reservation*, *premar-*

shalling, etc.) and on the method that computes the concrete pile for the relevant container (*random*, *category*, etc.). Here, solution strategies for the former decision problem are subsumed under the heading of *storage area division strategies* while methods for the latter decisions are termed *pile selection methods.* Altogether, a terminal's stacking policy is defined by the combination of the applied *storage area division strategy* and the used *pile selection methods* for the different container flows. While the *storage area division strategies* are just different strategic concepts for the subdivision of the storage space into areas for different storage purposes, the presented *pile selection methods* provide heuristic algorithms to determine the storage positions for incoming containers. In Figure 14.3, a classification of the described stacking approaches is given.

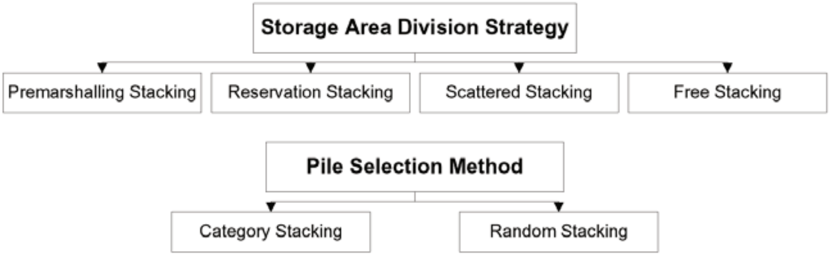

Fig. 14.3 Categorization of stacking approaches

14.3.3.1 Storage Area Division Policy

The merit of *premarshalling stacking* is the simplification of the stacking problem. Sophisticated stacking methods are not required for incoming containers since they are first more or less randomly stacked in a temporary storage area and only afterwards stacked in the *premarshalling area* in the order of the stowage plan. Due to this, a huge number of *premarshalling* moves is required before the arrival of the vessel, which is the major drawback of this strategy, as additional yard crane resources are needed. *Premarshalling* stacking is especially useful for SC or RTG operated yards, when accurate information on the containers and stowage plans are missing and thus many shuffle moves during the loading processes are expected. For RMG yards, *premarshalling* is only partly or even not at all applicable. Either temporary storage areas have to be defined in each block, or special temporary storage blocks have to be installed. Both are connected with operational problems, like the reduced exchangeability of containers between the RMG blocks and huge equipment resource requirements involved.

The benefits of *reservation stacking* are the separation of containers for/from different vessels, thus reducing the number of required shuffle moves. Furthermore, a realistic evaluation of the yard capacity is always available, since prospectively arriving containers are already incorporated in the storage statistics. But at the same time, this is also the main disadvantage of *reservation stacking*, because physically available slots are blocked, thus flexibility and a potentially higher yard utilization is lost. This strategy is applicable for RMG operated yards.

Scattered stacking tries to overcome these shortcomings by not assigning storage areas prior to the arrival of a vessel but only once to a certain berth. This concept results in a higher yard utilization, as no slots are occupied before the arrival of a vessel. Since certain blocks may be assigned to one berth, *scattered stacking* can be applied for RMG yards. But this may lead to an uneven utilization of the different yard blocks during the processing of a vessel, connected with several operational problems. The yard blocks may be overcharged in terms of yard crane capacity, resulting in a disturbed vessel processing. Furthermore, uneven block utilization is leading to problems in the horizontal transport management in terms of blocking or even deadlock situations.

To avoid these shortcomings, container terminals are expected not to assign blocks to berthing places. Moreover, they are expected to evenly spread import and export containers of a vessel over all yard blocks, which is called *free-stacking* here. Dekker et al (2006) do not explicitly describe such a policy, but due to the presented stacking methods, such a *storage area division strategy* is implicitly assumed.

Altogether, the last strategy seems to be most suitable for RMG stacking, since it offers the biggest opportunity to exploit the advantages of this modern yard crane system. But while other strategies simplify the concrete pile selection method, *free-stacking* postpones important parts of the stacking decision and hence makes the *pile selection methods* more important.

14.3.3.2 Pile Selection Method

The *pile selection method* is required to determine a concrete pile within the chosen yard block. A *pile selection method* has to deal with incoming import and export boxes, as well as required shuffle moves. Due to differing characteristics mainly concerning the available information, these three types of boxes are generally stacked differently. The literature overview reveals that to the best of the author's knowledge only one relevant *pile selection method* is known – *category stacking*. However, variations of *category stacking* with different characteristics have to be distinguished.

First of all, for each container type to be stacked, *i.e.* import, export and shuffle, the number of categories and the corresponding characteristics have to be decided. As already mentioned, a category of export containers consists of size, weight, vessel and port of destination. An additional categorization according to the shipping line of a container, as proposed by the *sort and store* strategy of Chen (1999), does not seem to be useful. In fact, it is possible for shipping lines to book transport capacities on vessels operated by other shipping lines. In addition, many oversea ship routes are served by alliances of shipping lines. Hence, it is standard that vessels are charged with containers of different shipping lines. Consequently, storing containers of different shipping lines in different stacks will not reduce the number of shuffle moves. To keep the number of categories for export containers at a required limit, the number of weight groups should comply with the minimum number required to ensure the stability of the vessel.

The number of categories of import containers is much smaller since hardly any useful information is available in order to anticipate the expected time of retrieval. Therefore, import containers generally cannot be stacked in the order of pick up and thus more shuffle moves than for export containers are expected anyway. Some terminals oblige or enable the trucking company to book certain time windows for the collection of a container in advance, which may enable stacking the corresponding import containers in a way that reduces the number of required shuffle moves. But in general, no or only uncertain information on the delivery time of import containers is known and the import modality thus forms only one category. Shuffle moves are generally stacked corresponding to their underlying modality, *i.e.* if the shuffled container is export, it is relocated to a pile of the same category, closest to its former position (vice versa for import).

Within the extending features for *category stacking*, proposed by Dekker et al (2006), the use of the ETD for export containers seems to be most promising for RMG yards. This feature allows to stack containers on top of piles for other vessels that will depart later than the corresponding vessel of the relevant container. Consequently, a higher yard utilization rate with no more resulting shuffle moves may be enabled by this feature, as more slots are available for containers to be stacked and shuffle moves are unlikely since the departure times of the containers are respected.

The departure time of a container can be approximated by the ETD of the corresponding vessel. However, in case of overlapping berthing times of two vessels, which is typical for larger container terminals, it is still possible that a container of the later departing vessel has to be loaded before containers of the earlier departing vessel. Hence, shuffle moves are likely to occur. For example, the estimated time of departure of vessel i can be later than that of vessel j, *i.e.* $\mathrm{ETD}_i > \mathrm{ETD}_j$, but in fact the loading operations are overlapping and shuffle moves can occur when stacking containers of vessel j on top of containers for vessel i. In order to avoid these shuffle moves, a buffer time β is proposed here as additional stacking criterion. The buffer time β is the minimum time lag between the ETDs of two vessel which is required in order to allow stacking containers of earlier departing vessels on top of containers of later departing vessels. In other words: stacking a container on top of a pile with containers that are designated for another vessel is only allowed if the ETD of the vessel for which this container is designated is at least the buffer time β before the ETD of the vessel for which the containers are designated that are already stored in that pile. Stacking containers for vessel j on a pile with containers for vessel i is only possible if $\mathrm{ETD}_i > \mathrm{ETD}_j + \beta$ is true. The higher the buffer time β, the fewer shuffle moves are expected, but on the other hand, the potential of the expected departure time as stacking criterion is reduced. Hence, the buffer period has to be chosen carefully.

In Figure 14.4 these explanations are illustrated. Containers of vessel B cannot be stacked on top of containers for vessel A, since the expected departure time of vessel B exceeds the boundary time (indicated by the dotted line) defined by the chosen buffer time β. But containers of vessel C are allowed to be stacked on top of piles for vessel A (but not B), as the expected departure time of this vessel is early enough before the time boundary of vessel A piles.

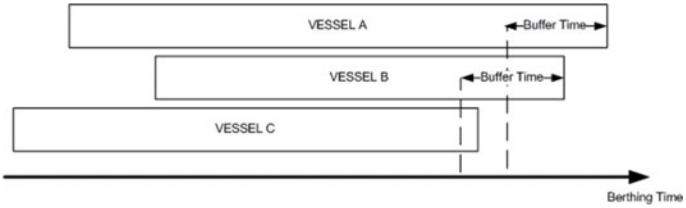

Fig. 14.4 Estimated departure time and buffer time as stacking criterion

Furthermore, Dekker et al (2006) propose a preference for slots close to the departure point of the containers, *i.e.* landside or waterside, since for outgoing containers accurate retrievals and reduced waiting times for the horizontal transport may be resulting. On the other hand, this strategy leads to longer waiting times for ingoing containers for the horizontal transport when applied during situations of high workload of the yard cranes. Hence, a workload-dependent *pile selection method* seems advisable. This might be described as follows: During situations of high workload at one side of the yard block, a container should be positioned close to the incoming side, *i.e.* the closest available slot with respect to the category of the container. In contrast, in situations of low workload, for incoming containers, a preference for slots close to the departure points should be applied. Moreover, the yard block can be reorganized during situations of low workload, *i.e.*, containers positioned close to the incoming side beforehand can be transported to an available slot close to the departure point. This process can be termed *prepositioning*. Thus, the crane workload can be smoothened and waiting times for the horizontal transport can be reduced. Besides a workload-dependent slot selection, a mutual decision of stacking and crane scheduling offers the possibility to create transport jobs with few empty driving times. On the one hand, an integrated solution offers the highest potential for optimization, but on the other hand, it makes the decision problem even more complex.

Based on these evaluations and the mentioned reason, it can be concluded that free stacking combined with *category stacking* seems to be most appropriate for RMG yard systems. Here, it is suggested to combine the aforementioned principles and extensions of *category stacking* in a weighted cost function that computes cost penalties for possible piles, *i.e.* piles for containers of the same length (20 ft or 40 ft) which have not reached the maximum stacking height.

The binary variables x_{bi} and y_{bi} indicate whether container i is outgoing at the other side than b (*i.e.* $x_{bi} = 1$, otherwise $x_{bi} = 0$) and whether i is of another category than b (*i.e.* $y_{bi} = 1$, otherwise $y_{bi} = 0$) respectively. The binary variable z_j indicates whether pile j is an empty pile (*i.e.* $z_j = 1$, otherwise $z_j = 0$), *i.e.* if container i will be stored on a ground slot. The variable d_{ij}^{In} and d_{ij}^{Out} give the crane driving distances from the ingoing handover position of container i to pile j and from pile j

to the outgoing handover position of container *i* respectively. The current workload situation of the yard block is indicated by the yard block occupation variable Occ, which is computed by dividing the number of yard crane transport jobs for that block that are currently awaiting execution by the number of averagely waiting transport jobs. The parameters α^{Mod}, α^{Cat}, α^{GS} and α^{Dist} are the user-defined cost factors for container storage on boxes with other outgoing side, for container storage on boxes with other category, for ground slot usage and for crane driving distances respectively. The costs c_{ij} for stacking container *i* in pile *j* may then be computed by

$$c_{ij} = \alpha^{\mathrm{Mod}} \sum_{b\varepsilon P(j)} x_{bi} + \alpha^{\mathrm{Cat}} \sum_{b\varepsilon P(j)} y_{bi} + \alpha^{\mathrm{GS}} z_j + \alpha^{\mathrm{Dist}} \left(\mathrm{Occ} \cdot d_{ij}^{\mathrm{In}} + \frac{1}{\mathrm{Occ}} \cdot d_{ij}^{\mathrm{Out}} \right)$$

The first term penalizes stacking container *i* on top of containers that are outgoing at the other side of the block than *i*. All boxes *b* stored in pile *j* (*i.e.* $b\varepsilon P(j)$) are checked for outgoing compatibility with container *i*. The second term penalizes stacking container *i* on top of containers with different categories. The usage of ground slots is penalized by the third term. The last term penalizes stacking container *i* close to the incoming side during situations of low workload ($\mathrm{Occ} < 1$) and during situations of high workload ($\mathrm{Occ} > 1$), stacking close to the outgoing side is penalized more.

The most appropriate pile for container *i* – in terms of the defined objective function – is then found by full enumeration, *i.e.* computing the stacking costs for all possible piles *j* and choosing the pile with the lowest costs. As the avoidance of mixed stacking of import and export containers is often seen as a primary objective, the cost factor α^{Mod} should be set very high, therewith dominating all other cost components. The cost factor α^{Cat} should also be set comparably high to ensure that distance or ground slot preferences do not have a bigger impact on the stacking costs than the avoidance of shuffle moves.

14.4 The Crane Scheduling Problem for RMG Container Yards

After a storage position has been chosen for a container, it has to be decided which crane transports the container to its designated pile and at what time this transport job takes place. Strategies and methods concerning this question are treated in this section. First, the objectives and constraints of the crane scheduling problem are explained for different RMG systems. Afterwards, a literature overview on crane scheduling approaches is given and finally, the presented strategies and methods are classified and evaluated.

14.4.1 Problem Description

The problem depends on the number of cranes operated per yard block. In case of one crane per yard block, only the sequence of known jobs has to be decided. The scheduling problem for a single crane is thus equivalent to the well known traveling salesman problem, which is characterized as NP-hard. In case of two or three cranes per block, the scheduling problem is even more complex, since not only the sequence but also the assignment of cranes to jobs has to be made.

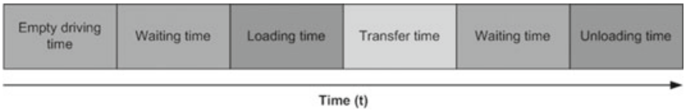

Fig. 14.5 Time components of transport jobs of gantry cranes

From the vantage point of a gantry crane, each transport job contains the same time components. These components are listed in chronological order in Figure 14.5. The distance between the end location of the previous job and the pick up location of the current job requires the crane to do an empty move. The related time component is called *E*mpty *D*riving *T*ime (EDT). Only in case of identical end and start locations of two successive jobs, no EDT is necessary. Such situations are sometimes called *double-play* or *dual-cycle*. Early arrival at the pick up location of the current job may lead to waiting time for the crane, if the container to be picked up is not ready yet. This is the case if the container has not yet been supplied by external trucks or internal vehicles or if another container has to be shuffled (by another crane) before the current container can be picked up. On the other hand, late arrival may cause delay in the vessel loading process and dissatisfaction on the customers' side. After picking up the container, the crane travels from the start to the end location of the job, where the container is unloaded. Once again, depending on the end location, early arrival may cause waiting time for the cranes and late arrival may have a negative impact on the adjacent transport systems. In case of two or three cranes per yard block, dynamic crane interferences may cause prolonged EDT and transfer times.

The controllability of the time components by scheduling decisions is indicated by the background color in Figure 14.5 While the loading and unloading times are not controllable, which is indicated by a red background, EDT and waiting times greatly depend on the scheduling decisions, which is indicated by the green background color. The transfer distance is fixed by the start and end location, but as the transfer time may depend on the amount of crane interferences, the transfer time is at least to some extent influenced by scheduling decisions.

As for most companies, the overall objective of container terminals is profit maximization. This objective is generally reached by maximizing the terminal throughput (TEU/year) with given resources. One of the key measures for throughput maximization is the minimization of turn around times of vessels, as this enables more vessels to berth and satisfies the terminal's most important group of stakeholders –

the shipping lines. But it is often difficult to identify the objectives for sub-systems, which support the objectives of an overall system in which the sub-systems are embedded. This is also the problem here: at least it is questionable which performance indicators of RMG systems are most important in order to enhance the aforementioned overall terminal objective.

Terminal operators often pay a lot of attention to the block productivity, which is generally measured by the number of productive jobs (excluding shuffle and prepositioning jobs) performed per operating hour. But the block productivity is not the sole performance indicator, since it is not necessarily aligned with the minimization of turn around times of vessels. Short turn around times require an undisturbed flow of containers to and from the quay crane. Thus the horizontal transport system is of great importance and waiting times for horizontal transport machines at the RMG blocks have to be avoided, because this directly leads to delays in quay crane supply. But since the maximization of block productivity is achieved by minimizing the transport times per job of the cranes, which do not consider the due dates of certain jobs, waiting times of horizontal transport machines are not necessarily minimized by this objective. In fact, some jobs may be retrieved late compared to the given due date, directly leading to waiting times for horizontal transport machines and quay cranes. Therefore, synchronization with the horizontal transport (*i.e.* minimizing late arrivals of the yard cranes) is at least as important an objective as maximizing the block productivity.

In addition, the maximization of the block productivity cannot be directly operationalized. The main precondition to ensure high block productivity is an efficient use of crane resources. Therefore, empty driving and crane waiting times due to early arrivals have to be minimized. Furthermore, minimizing EDT reduces the energy consumption of yard cranes, which satisfies overall financial and ecological objectives.

It is assumed that each job j is connected with a certain due date d_j, which defines when the assigned gantry crane has to arrive at the pick up location of the corresponding container. If a_j is the estimated arrival time of the assigned gantry crane at the pick up location of job j, lateness L_j and earliness E_j are defined as

- $L_j = a_j - d_j\,,\, a_j \geq d_j$
- $E_j = d_j - a_j\,,\, d_j \geq a_j.$

Overall, the following operational objectives for the yard crane scheduling problem are identified.

- Min L_j Minimization of late arrival at the pick up location of job j
- Min E_j Minimization of early arrival at the pick up location of job j
- Min EDT_{ij} Minimization of EDT from the destination of job i to the pick up location of job j

14.4.2 Literature Overview

An extensive overview regarding crane transport optimization is presented in the literature overview on terminal operation by Stahlbock and Voß (2008). A detailed analysis of the presented references reveals that the number of available references is somehow unbalanced. While a broad range of scheduling literature is available for RTG crane systems, only few references are available for RMG systems. Within this section, an overview of strategies and methods for crane scheduling and related problems is given. Besides pure yard crane references, some literature on more general operations and machine scheduling problems is also presented.

The pioneers in RTG crane scheduling are Kim and Kim (1997, 1999) who published the first mixed-integer model for routing a single crane within one yard block and presented an optimal algorithm for this model. In the last years, the field of RTG scheduling has been intensively investigated. Several mixed-integer models have been published that allow the scheduling of two or even more yard cranes per block (see, *e.g.* Ng (2005), Lee et al (2006), Jung and Kim (2006) and Lee et al (2007)). These models are mostly solved by greedy heuristics or metaheuristics like simulated annealing or genetic algorithms. However, as argued in Section 14.3.2, scheduling strategies for RTG systems cannot be applied to RMG systems.

The work published by Cao et al (2008) deals with the deployment of *double* RMG crane systems. But since they assume a truck lane in parallel with the yard block for loading and unloading processes, the logistics concept is more similar to that of typical RTG systems.

A group of authors presents some more strategically oriented works on RMG crane systems. Saanen and Valkengoed (2005) compare *single*, *twin* and *double* RMG systems. They evaluate the systems by means of simulation in terms of land utilization, throughput, flexibility, complexity and cost. They find that the *double* RMG system appears to be the one performing best, but it occupies the highest amount of land. For crane scheduling, they apply simple heuristics like the FIFO and *N*earest *N*eighbor (NN) priority rules. Valkengoed (2004) makes a comparative simulation study between the *twin* and *double* RMG systems. She also applies simple priority rules like NN and the *E*arliest *D*ue *D*ate (EDD) rule for crane scheduling. The results show only minor differences between the different cranes and scheduling rules, but the *double* RMG system apparently offers a higher waterside productivity.

A more operational oriented work on RMG systems has been published by Zyngiridis (2005), who develops integer linear programs for scheduling *single* and *twin* crane systems. Besides crane scheduling, the model also covers the container stacking problem. The author formulates the objective function to be maximized of stacking as many import containers as possible in the best available positions. Late arrivals compared to the due dates are prohibited by the model restrictions. To reduce the problem complexity, shuffle moves are not explicitly considered, but for each import or export job, a fixed amount of time is reserved to shuffle containers above the required one. For the numerical tests, the author assumes a planning horizon of fifteen minutes, *i.e.* the transport jobs occurring within the next fifteen minutes are known. Furthermore, jobs coming in during the execution of a crane schedule are ignored, *i.e.* the *ignore* online strategy is applied.

Choe et al (2007) investigate the scheduling problem for *twin* RMG systems, laid out perpendicularly to the quay wall with handover positions located only at the block ends. They assume that waterside storage and retrieval jobs can only be served by the waterside crane, while landside jobs can only be served by the landside crane. Different degrees of crane cooperation and scheduling methods are investigated by simulation experiments. The degree of crane cooperation is defined by the yard block zone in which a crane is allowed to execute shuffle jobs required by productive jobs of the other crane – the greater the zone, the more crane cooperation. As scheduling method, the simple priority rules EDD and NN, as well as two metaheuristics (simulated annealing and hill climbing) are proposed. The performance is evaluated in terms of waiting time for AGVs and external trucks at the handover positions. The results reveal performance advantages for a higher degree of cooperation and for the application of metaheuristics.

Kemme (2009) and Stahlbock and Voß (2010) study the problem of scheduling *double* RMG crane systems for a similar block layout, like the one considered by Choe et al (2007). In both studies the scheduling performance is evaluated in terms of block productivity, as well as resulting waiting times for horizontal transport machines.

In Kemme (2009) crane scheduling is done by different greedy priority rules, as well as optimal full enumeration. The resulting optimal schedules are applied with both the online strategies *replan* and *ignore.* By means of a simple simulation tool, it is investigated which crane scheduling objectives and scheduling methods best support the overall terminal objectives in an online situation. In addition, the effects of varying look-ahead horizons and workload situations are considered by sensitivity analysis. The results reveal that the performance of single objective priority rules like EDD and NN can clearly be improved by the usage of optimal online scheduling methods and multi-criteria objective cost functions, which consider the minimization of the weighted sum of EDT, as wells as early and late crane arrivals. Only minor improvements in terms of block productivity are observed, but significant reductions of late arrivals are achieved, especially by the application of the *replan* strategy.

Stahlbock and Voß (2010) propose different heuristics like greedy priority rules (*e.g.* FIFO, EDD) and simulated annealing for crane scheduling within a *double* RMG system. For the simulated annealing approach the schedules are evaluated by a cost function that considers the weighted sum of EDT, as wells as early and late crane arrivals. Stahlbock and Voß (2010) pay a lot of attention to a quite realistic consideration of crane interferences for which they suggest several formulas. By means of a simulation model that is close to reality, the performance of these scheduling methods is evaluated. Similar to Kemme (2009) only minor improvements of the block productivity are observed, while notable waiting time reductions for the horizontal transport machines are found, particularly in situations of high workload. Here, these performance improvements are obtained by the usage of simulated annealing. In addition, several valuable ideas for container stacking, crane scheduling and combined solutions of both planning problems are given.

Altogether, only few references are currently available which are directly related to the crane scheduling problem investigated here. Therefore, literature on comparable problems, as well as references to the general machine scheduling problems are examined for applicability. In fact, an automated RMG container block can be regarded as a special type of the general logistic concept of *A*utomated *S*torage and *R*etrieval *S*ystems (AS/RS). This concept refers to relatively complex computer-controlled storage systems, which are integrated into manufacturing or warehousing processes. AS/RS have been operating successfully in hundreds of manufacturing and distribution centers since the early 1960s, well known examples are automated high-rise storage racks. Consequently, strategic and operational planning problems of AS/RS are comparable to those of RMG blocks and it is therefore worth examining AS/RS-related literature. Several overviews on AS/RS planning problems are available (see, *e.g.* Sarker and Babu (1995) and Rouwenhorst et al (2000)). There is a broad range of AS/RS in terms of input-output-positions (*i.e.* handover positions for RMG blocks) as well as capacity and number of order-pickers (*i.e.* gantry cranes for RMG blocks). Randhawa et al (1991) and Bozer and White (1990) consider AS/RS with two input-output-positions at the ends of the aisles. For scheduling, the *F*irst-*C*ome-*F*irst-*S*erve (FCFS) and NN priority rules are applied. Performance advantages of the NN rule compared to FCFS are reported by Eben-Chaime (1992).

Vis (2002) studies the problem of scheduling AS/RS in general and for the special application of automated storage yards at container terminals. Known methods are reviewed and a new scheduling policy for a unit load AS/RS is presented and tested for container yards. She differentiates between block and dynamic scheduling concepts, which are comparable to the online strategies *ignore* and *replan* respectively. Her review of existing AS/RS scheduling methods reveals that the block scheduling problem is mostly treated as an assignment problem with the objective of minimizing empty travel times, whereas the dynamic sequencing problem is mostly solved with priority rules. Vis (2002) develops an algorithm that solves the travel time minimization problem for a unit load AS/RS system with multiple aisles and handover positions at both ends of the aisles to optimality. This algorithm is applied in a simulation study for scheduling a single RMG crane.

Finally, the problem of scheduling RMG gantry cranes can be regarded as a special type of the general machine scheduling problems. For instance, the scheduling problem for the *double* RMG system can more generally be regarded as scheduling two identical machines with arbitrary processing times, release times (defined by the due date) and setting-up times (represents EDT). Even without the complicating job characteristics of release and setting-up times, these scheduling problems have been identified as NP-hard (see MacCarthy and Liu (1993)). As regards *twin* or *triple* crane systems, the scheduling problem is even more complicated, since the machines cannot be treated as parallel identical ones, due to the increased crane interferences, but as parallel heterogeneous machines. Several introductions and literature overviews on scheduling research in general are available (see MacCarthy and Liu (1993)). In addition, Cheng and Sin (1990) provide a special survey of major research results in parallel machine scheduling theory. It turns out that by today, hardly any source is directly related to the scheduling problems addressed here.

14.4.3 Classification and Evaluation

According to the previous sections the crane deployment problem may be subdivided into two successive problems. First, it has to be decided for each job which crane(s) is(are) allowed to perform the job. This is trivial or even unnecessary for the *single* system, but for multi-crane systems different decision strategies are possible. In the following, this decision problem is referred to as *preselection*. Depending on the *preselection* strategy, the resulting sets of executable jobs for each crane may be overlapping, *i.e.* some jobs may be done by several cranes, while others may only be performed by a single crane. Based on these sets of executable jobs for each crane, in the next step, the jobs are exclusively assigned to cranes and crane related sequences are built. This process step, which is called *dispatching* here, can either be done successively or simultaneously. Altogether, a terminal's crane scheduling policy is then defined by its *preselection* strategy and its *dispatching* method. In Figure 14.6, the interaction of *preselection* method and *dispatching* method within the framework of crane deployment policies is illustrated. Detailed explanations for the shown classification of online *dispatching* methods are given in Section 14.4.3.2.

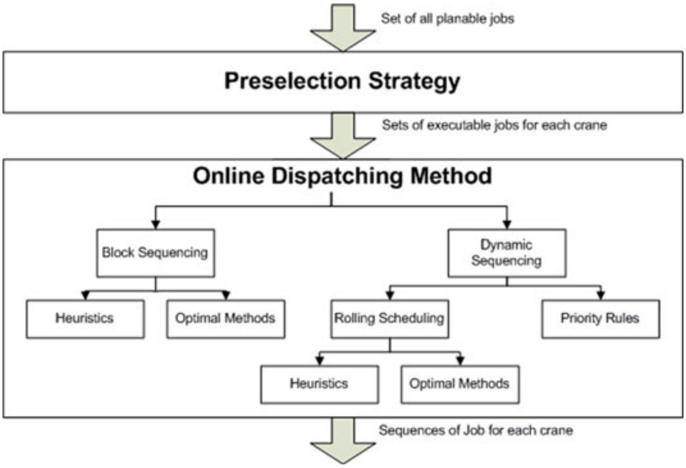

Fig. 14.6 Functionality and classification of crane scheduling policies

14.4.3.1 Preselection Strategies

The decisions for the *preselection* problem are made based on operational objectives and technical restrictions. The latter occur in the *twin* and *triple* systems, where the two identical cranes cannot pass each other. Consequently, jobs connected with the waterside handover positions can only be executed by the crane which is closer to the waterside and vice versa for the landside. The operational objectives are the avoidance of crane interferences in order to secure only short waiting times at the handover positions. This is especially important for the waterside handover positions, since an undisturbed vessel processing is generally judged as more important than truck operations (see Choe et al (2007)).

Within the framework of the *preselection* problem, productive and assisting jobs have to be divided. While productive jobs (storage, retrieval) are always connected with a handover position, thereby defining the feasible crane, an assisting job (shuffle, prepositioning) cannot generally a priori be assigned to a certain crane. Thus, a *preselection* strategy is most of all defined by the assignment of assisting jobs. Here, four general *preselection* strategies are suggested. The actual arrangement depends on the respective crane system.

PS1 is characterized by the greatest possible cooperation between the cranes. Depending on the crane and the crane system at least all assisting jobs can be executed by all cranes.

PS2 is defined by only small or even no crane cooperation. Each crane is assigned to a certain handover position and only executes productive and assisting jobs which are connected with the respective handover position.

PS3 focuses on the waterside performance. One (or even two) crane(s) is(are) exclusively assigned to the waterside handover positions and the other crane(s) execute(s) waterside and landside jobs.

PS4 is defined by zones for each crane. All jobs occurring in that zone can be executed by the assigned crane. Overlapping of different crane zones is allowed. The extent of crane cooperation and crane interferences depends on the customization of the zones.

14.4.3.2 Dispatching Method

The outputs of *preselection* strategies are sets of executable jobs for each crane, which are the input for the *dispatching* methods. According to the literature overview, *dispatching* methods can be distinguished into block sequencing and dynamic sequencing methods, as well as heuristics and optimal methods. Within dynamic sequencing, rolling scheduling methods and priority rules also have to be distinguished. While rolling scheduling methods compute complete schedules, including all known jobs, priority rules only assign the next job to the calling crane.

The literature overview reveals that in most cases priority rules are used as *dispatching* methods, which is mainly explained by the plain functionality of these methods and the complexity of the underlying scheduling problems. Applications of the NN rule, the FCFS rule and the EDD rule are reported. Without any modifications, all of them are applicable to *single* and multi-crane systems. However, since jobs do not always come to be known in the order of the corresponding due dates, the FCFS rule does not even support the objective of minimizing late arrivals and thus does not comply with any of the yard crane objectives. In addition, with NN only the minimization of empty driving times is pursued and EDD only tries to avoid late arrivals. Hardly any performance comparisons of priority rules for scheduling of automated yard crane are available. Kemme (2009) reports a superior performance of EDD compared to NN for the *double* RMG system. Moreover, a combined priority rule considering EDT and late arrivals is considered, which leads to even better results.

In deterministic planning situations optimal methods lead to equal or better results (in terms of objective function) than heuristics and priority rules do, but in online situations, as in crane scheduling, this is not a priori true. Moreover, it is questionable whether higher computational effort really leads to an improved performance. Consequently, only a few authors investigate optimal *dispatching* methods for RMG yard crane scheduling (see Section 14.4.2). The linear model proposed by Zyngiridis (2005) is based on several simplifying assumptions, which are not in line with the operational objectives formulated here. In addition, the model is developed for *single* and *twin* system, which do not allow for a straightforward adaption for *double* and *triple* systems. Vis (2002) presents a method which only supports the empty driving time minimization objective. In Kemme (2009), optimal schedules for the *double* system are computed by full enumeration of multi-objective functions, which seems only applicable if few jobs have to be scheduled, since otherwise the method does not comply with the real-time requirement. Another drawback of this study is that crane interferences are not considered. In contrast, the simulated annealing approach presented by Stahlbock and Voß (2010) explicitly considers crane interferences for *double* systems and it is able to produce quite good schedules in real-time compliant periods of time. However, the resulting schedules may be distorted insofar as crane driving times and interferences are computed on basis of simplifying assumptions. Choe et al (2007) presents a method based on metaheuristics which minimizes late arrival for the *twin* system. Only little information on the functionality of the method is given, but significant improvements compared to the priority rules EDD and NN are reported.

A general preference for block or dynamic scheduling cannot be given. Which online concept leads to a better performance clearly depends on the actual problem setting and various parameters. However, while Zyngiridis (2005) uses block sequencing, Choe et al (2007) and Kemme (2009) report good results for dynamic sequencing.

In total, the available literature shows promising performance improvements for *twin* and *double* systems by applying more sophisticated *dispatching* methods than priority rules. In particular, the application of metaheuristics seems to be very promising, as quite good schedules may be produced within reasonable computation time. Furthermore, it seems plausible to expect that such approaches also lead to good results for the other RMG systems. In the next section, the impact of the operational stacking and crane scheduling approaches on strategical terminal planning decisions is explained in detail.

14.5 Strategical Relevance of Stacking and Scheduling Strategies

Strategic decisions have to be made for the long term. Within the framework of container terminals, these decisions are termed as terminal planning. The key problems in terminal planning are decisions on the terminal layout, as well as decisions on the type and number of equipment. The extent of terminal planning decisions depends on the problem type, which can be a new development, an extension or a change of the current system. Subsequently, it is explained that decisions on operational planning problems like container stacking and yard crane scheduling have notable effects on terminal planning decisions.

Terminal planning can be done in several ways. Mainly static and dynamic terminal planning have to be distinguished. The former does not consider all dependencies between different decisions and stochastic performance influences are often neglected. In practice, static terminal planning is mainly based on mean values and risk-dependent surcharges, called peak factors. In dynamic terminal planning, which is generally done by means of simulation, it is tried to consider dependencies and stochastic performance influences. The latter can be done by distribution assumptions on equipment performances or by explicitly modeling the dynamically interdependent behavior of terminal machines.

No matter how terminal planning is done, in each case decisions on operational problems play a vital role. The only difference between the terminal planning types is the way in which effects of operational decisions are considered. In case the equipment behavior is explicitly modeled, their performance directly depends on the underlying operational strategies and methods. Here, the number of shuffle moves depends on the stacking policy and the empty driving times, as well as crane interferences depend on the applied crane deployment policy, both influencing the crane performance indicators of punctuality and productivity. Otherwise, if operational decisions are not explicitly modeled, different stacking strategies and crane deployment policies have to be reflected by changing mean performance values or distribution functions.

Since the storage yard is the center of the terminal where most processes originate or terminate, more than just planning decisions on the storage yard are influenced by stacking and crane deployment policies. Obviously, the number of yard cranes needed is directly influenced by the applied policies and the resulting crane performance. Consequently, the number of yard blocks and the layout is also influenced by the operational decisions. Moreover, the number of required transport vehicles between quay cranes and storage yard is also affected by the decisions on stacking and scheduling. Even the number of quay cranes and the dimensions of the hinterland gate facilities are to some degree implicitly influenced by these decisions. Subsequently, these connections are illustrated with some small numerical instances.

Assuming a total yard crane performance of 275 jobs/h is required at the waterside during peak situations, then an increase in the block productivity from 25.00 to 26.25 jobs/h may reduce the number of required yard blocks by 5%. Alternatively, one can assume that such an improvement in the block productivity enables an increase in the average stacking height from 3.00 tiers to 3.15 tiers without any performance losses involved. Consequently, in a storage yard with a required capacity of 25,200 TEU, the number of ground slots can be reduced by 400 slots. Thus, the block layouts can be modified, allowing for savings in required storage area. Furthermore, by improving the yard crane punctuality at the waterside by 30 seconds per job on average, theoretically allows to reduce the number of employed AGVs by two, if 16 yard blocks are in operation with an average of 15 waterside jobs per hour each. But since a container terminal is a very complex system, these numerical examples are overly simplified insofar as not all effects and interdependencies of operational improvements and system changes are considered. However, the importance of operational storage decisions is illustrated by these numbers.

In summary, it has been shown that stacking and crane deployment policies, as studied here, indeed have remarkable effects on terminal planning decisions. By reducing shuffle moves, empty driving times and crane interferences, the crane productivity and punctuality can be improved, leading to reduced area and equipment requirements, not just for the storage yard, but also for the related subsystems.

14.6 Summary and Conclusions

The operational planning problems of container stacking and yard crane scheduling for RMG systems laid out perpendicularly to the quay wall with handover positions only located at the waterside and landside block ends is regarded here. For both problems the objectives are identified, literature overviews on existing planning strategies and methods are given and these approaches are evaluated and categorized.

For the stacking problem the minimization of required shuffle moves is identified as principal aim. Existing stacking approaches are classified in *storage area division strategies* and *pile selection methods*. For RMG systems the *storage area division policies* of *free stacking* is expected to perform best. For the implementation of *category stacking*, which is the most relevant *pile selection method*, an objective function is proposed, which allows the flexible consideration of additional objectives.

Punctuality and productivity are identified as main objectives for the crane scheduling problem. Here, the decision process is divided in a *preselection* strategy and an online *dispatching* method. For the *preselection* strategy some concepts are proposed. Even though only a few authors investigate other online *dispatching* methods than priority rules, superior performance is expected by more elaborated *dispatching* methods.

Finally, the effects of container stacking and crane scheduling decisions on strategical terminal planning are explained. It is concluded that decisions on both operational planning problems have significant effects on several strategical terminal planning decisions. Not just layout and equipment decisions for the storage yard are affected, also equipment decisions for the related subsystems are notably influenced by these operational storage yard problems.

Further research on the issue of RMG yard crane scheduling and container stacking seems to be badly required and should be devoted to more sophisticated *dispatching* methods for multi-crane systems. In addition, a comparable analysis of stacking and crane deployment policies is recommended.

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Part V

Planning Area

Terminal Landside & Hinterland

Chapter 15
Opportunities to Exploit Capacity Reserves of the Hinterland Connection to Road Transport

Stefan Geweke and Frank Busse

Abstract
Looking at the modal split for hinterland transport of most big seaport container terminals of the north range, the average portion of the truck is 63%. Hence, road transport is the dominating mode concerning hinterland connections. In order to organize efficient cargo flows at the terminal and to provide a good service to its customers, the terminal operator could take several measures to create a good hinterland connection to road transport. For example, a better integration and usage of information technology may improve data quality resulting in more efficient truck handling at the terminal. Furthermore, slot booking systems and pre-gates may smooth the load curve over a day and help reduce congestion on the road. In addition, together with other stakeholders the terminal operator could contribute to the development of truck guidance systems and support other transport modes to discharge the road capacity.

15.1 Challenges to Connect Seaport Container Terminals to Road Transport

The quality of inbound and outbound hinterland transport systems is crucial to the performance and competitiveness of a *S*eaport *C*ontainer *T*erminal (SCT). It could be measured by *e.g.* the best possible ratio of high speed, high reliability and low

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cost in accordance with customers requirements. The importance of a good hinterland connection becomes visible by having a look at the cost portions comparing sea to hinterland transport.

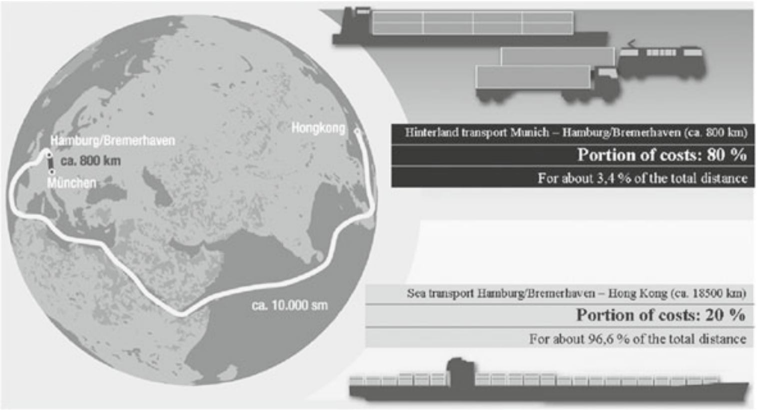

Fig. 15.1 Comparison of transport costs (see IHK Nord (2009))

As shown in Figure 15.1 sea transport concerns only about 20% of the whole transport costs per container considering the connection Munich – Hong Kong. However, the distance traveled with the ocean carrier refers to about 96.6% in relation to the distance traveled over land. The figures refer to the year 2008 and have been calculated by the Chamber of Commerce in Hamburg (see IHK Nord (2009)).

Even though mass transport systems, such as inland waterways and railways, are important to serve long distance travel, generally, the highest share of the modal split refers to road transport. Figure 15.2 shows the portions of road, railway and inland waterway transport of some big north range SCT (see HPA (2008)). For all regarded seaports, the truck is the most important means of transport in terms of the inbound and outbound hinterland connection, getting a share from about 58% in Rotterdam to 89% in Le Havre. The average portion of road transport within the north range SCT is about 63%. Hence, it is crucial for SCT to provide a good connection to the road transport system.

The big advantages of the truck are speed and flexibility. In addition, the complexity of railway and inland waterway transport increases due to additional handling operations and the necessity of bundling, that lead to more coordination and communication processes. Furthermore, the train or vessel operator always faces the problem of getting a high and stable capacity utilization because the train or vessels are bound to timetables that cannot be changed within a short time. After all, usually an extra road transport service with additional handling is needed on the last and first mile, respectively. In contrast, mass transportation is able to divide the total costs of transport by each container, which leads in comparison to road transport to a lower price per unit the longer the traveled distance is. According to these assumptions the truck often is more competitive on short distances up to about 300 km to 400 km[1], *e.g.* in terms of the port of Hamburg.

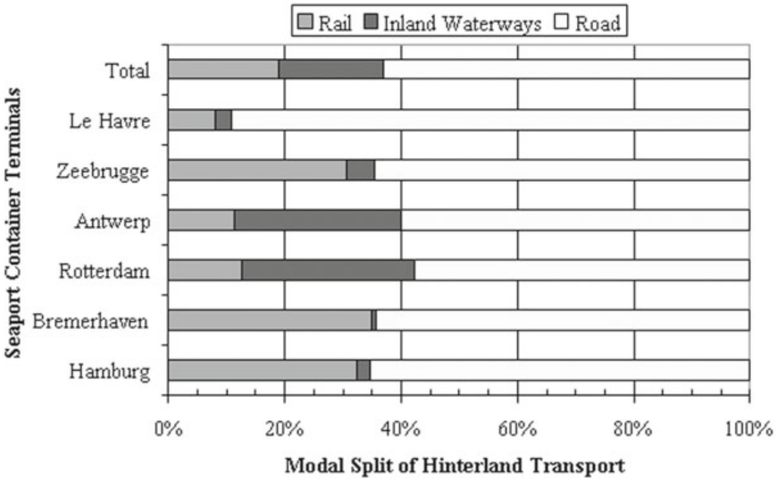

Fig. 15.2 Modal split of hinterland transport (see HPA (2008))

Nevertheless, there are several other stakeholders besides the terminal operator having interests in the road transport system (*e.g.* the public or port authorities in charge with the infrastructure, the trucking companies and forwarders, the truck drivers, the employees of organizations being located in the harbor, as well as other road users such as transit traffic, including both passenger and freight transport). In addition, from the SCT point of view, none of the stakeholders mentioned above including trucking companies is one of its direct customers. Thus, the management of SCT may tend to focus on their direct customers first, which are the ship operators and all relating processes, such as container handling at the quay and yard storage. However, SCT should focus on good hinterland connections to be able to use the highest possible capacity of the terminal and to satisfy the final customer of the transport chain being the customer of the haulage contractor who uses the seaport for container handling.

Finally, the connection of a SCT to road transport could be divided in two parts. Firstly, it is the handling of trucks at the terminal that could be influenced directly. Secondly, there is the condition of roads that belongs to the public authorities and lie outside the direct control of SCT operators. Thus, the question is how far the SCT management could be involved and which measures they could take to improve hinterland connections to road transport.

The remainder of the paper is structured as follows. Section 15.2 describes the general process of road transport starting or ending at a SCT. Subsequently, the authors analyze the capacity of the hinterland connection to road transport in Section

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[1] See Schinas and Dionelis (Chapter 20, Section 20.4.2, page 411 of this Handbook).

15.3. Section 15.4 is about measures to improve the processing of trucks at a SCT. Finally, a brief conclusion summarizes the findings of this article in Section 15.5.

15.2 General Process of Road Transport Starting or Ending at the Seaport Container Terminal

Figure 15.3 shows the general process of truck handling at a SCT starting with an advance notice (1) via *E*lectronic *D*ata *I*nterchange (EDI). When the truck arrives at the terminal (2), it has to stop at a parking area outside the gate if the driver has to get out for a personal check-in (3) for authorization and security purposes. After having registered at the interchange the truck moves on to the in-gate for the physical container check (4) including *e.g.* the inspection of the container and seal number, the general condition, as well as further safety and security issues. If the vehicle does not bring any container, the driver is able to enter (5) the SCT without any further physical checking procedure.

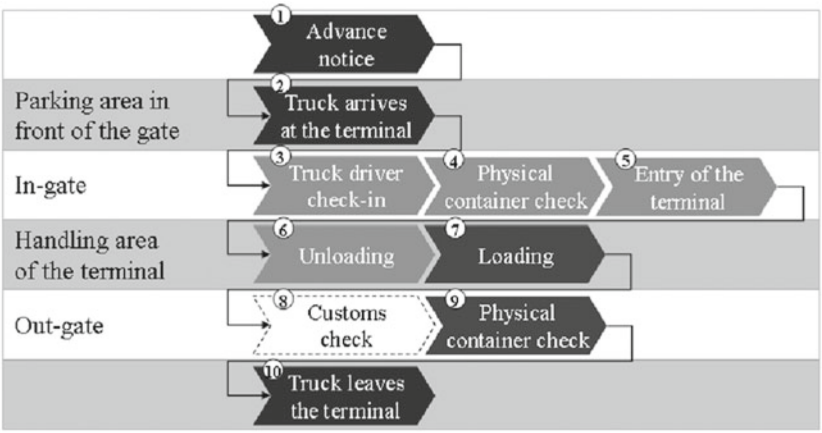

Fig. 15.3 General process of truck handling

Arriving at the handling area of the terminal the ingoing container has to be unloaded (6) before an outgoing box can be taken (7). Then, customs checks (8) may be necessary at the terminal, if it is not located in a free port zone. Finally, a physical check (9) has to be carried out at the gate before the truck is allowed to leave the terminal (10) with a container. If the vehicle wants to depart without any cargo, no extra checking procedures are needed.

15.3 Capacity Analysis of the Hinterland Connection to Road Transport

The capacity of terminal hinterland connection based on road transports is determined by possible bottlenecks within the process. Hence, congestion may occur either during truck handling at the SCT or outside the terminal using the public road infrastructure. The capacity of the road network usually lies outside the responsibility and influence of the SCT operator. However, the management is able to take measures to improve the processing of trucks in the harbor as shown in Section 15.4.

15.3.1 Terminal Capacity of Truck Handling

The terminal throughput of trucks is primarily limited by the capacity of the truck gate as a road-related system interface, as well as the capacity of the handling (or holding) area, which enables a systematic container exchange between trucks and terminal equipment close to the yard area. Depending on the type of technology used for the container storage, there are several possibilities to hand over a box using *e.g.* straddle carriers or gantry cranes. Considering truck handling procedures at SCT gate processing often turn out to be the bottleneck within the overall process. In order to achieve high resource efficiency, the interactions between gate, holding area and other related working steps have to be integrated and fine-tuned. A best possible solution could be found by *e.g.* using simulation tools to organize the whole process (see, *e.g.* Huynh and Walton (2007)). Due to changes in load requirements (over time) typical peak hours of truck arrivals and departures should be included in the dimensioning of gate structure and associated handling facilities. Assuming a “typical” (instead of a “maximum”) peak situation avoids oversizing of terminal resources and guarantees a smooth handling process for the majority of operations cases.

15.3.1.1 Gate Capacity

The maximum capacity or rather productivity of the gate processing could be measured by the amount of trucks per time unit, *e.g.* one hour, that are able to enter the SCT. In addition, truck lead times at the gate sub-stations, such as “interchange offices” and “in-/out-gates” determine the process quality. Figure 15.4 shows typical truck handling at a gate of a SCT in Long Beach, USA, where employees are checking containers physically. Generally, the following factors determine the gate capacity. They could be structured by the degree of direct influence of the SCT:

1. Direct responsibility of the terminal management, *e.g.*

- number of gate lanes,
- number of workstations (or employees respectively) for container registration,

Fig. 15.4 Lanes of a truck gate

- number of personnel responsible for the checking procedures,
- outline and duration of the checking process per truck,
- number and type of employed (IT) equipment like handheld devices for checking staff or self-service terminals for truck drivers.

2. Frequently, not, or only partially within the sphere of influence of the terminal management, *e.g.*

- portions of trucks carrying full, empty or no containers,
- portion of spot checks by customs authorities, if the SCT lies outside a free port area,
- integration of *I*nformation and *T*elecommunication (IT) systems and data quality,
- portion of trucks that have been noticed in advance and possible mistakes or missing data could be clarified before the arrival at the gate.

In addition, the size of the parking lot in front of the terminal gate is an indicator of the quality of truck handling. Usually, it has no impact on the productivity of the terminal processes because its main function is to buffer arriving trucks. However, it will influence traffic conditions on public roads in the harbor area, if in worst cases the capacity is not sufficient. Thus, it may influence the public perception leading to a bad image of a SCT as the origin of traffic jams.

15.3.1.2 Handling Area Capacity

The capacity for unloading and loading of containers is another important stage of the transport process that may become a bottleneck. Generally, the truck handling area on a SCT could be operated by *e.g.* straddle carriers (a) or *R*ail-*M*ounted *G*antry (RMG) cranes (b). If space is not an important issue containers could be directly stored on trailers (c). Thus, truck handling at the terminal would be reduced to connect or disconnect loaded or unloaded trailers. The following outline will describe the system variants in more detail.

(a) Container yard mainly operated by straddle carriers

Usually, there is a special area where trucks could wait to deliver or load boxes, if there is a container yard mainly operated by straddle carriers. The handling capacity of mainly straddle carrier operated container yards often depends on the following factors:

- size of the handling area and corresponding number of service lanes,
- number of used straddle carriers and their load factor in terms of combining loading and unloading of trucks with one way back and forth,
- average distance from the container yard to the handling area
- decision support systems to automate and improve the disposition of jobs and routing of vehicles.

Fig. 15.5 Truck serving straddle carriers crane

For example, Figure 15.5 shows straddle carriers serving trucks at the HHLA container terminal Tollerort in Hamburg, Germany. The trucks are waiting in several parallel lanes next to the container yard.

(b) Container yard mainly operated by RMG cranes

If the container stock of a SCT is structured by several RMG blocks (being arranged perpendicularly to quay wall) the handling area to connect the hinterland is located at the landside end of storage blocks. The other end belongs to the quayside operations area enabling vessel loading/discharging. For example, Figure 15.6 shows the handling area for road transport at the Container Terminal Altenwerder in Hamburg, Germany. In case of trucks being directly served by RMG cranes belonging to one storage block, the capacity of truck handling especially depends on the following factors:

- number of storage blocks and corresponding service lanes for truck handling
- utilization of the container block (the higher the utilization the higher the probability of additional shuffle and housekeeping moves and therefore more handling time for trucks),
- utilization of the RMG cranes due to parallel vessel or train handling operations (competition between the different transport modes increases handling times for trucks)
- decision support systems to automate and improve the planning and dispatching of jobs.

Fig. 15.6 Truck handling by a RMG crane

However, the layout and processing of truck handling may differ slightly from one solution to the other. For example, the container yard of the ECT Delta Terminal in Rotterdam is structured by storage blocks and operated by RMG cranes, too. But regarding the handling of trucks at the side to the hinterland one additional move by straddle carriers is necessary. Thus, in addition to the aforementioned aspects the restrictions of the straddle carrier variant must be taken into account to define the capacity of truck handling.

(c) Container yard operated by truck trailers A third alternative of container storage is shown on Figure 15.7 referring to the port of Long Beach, USA. In this case truck trailers loaded with boxes are directly stored in the yard that is connected via truck-trailer combinations to both sides such as the sea and the hinterland.

Considering STCs with a container yard solely operated by truck-trailer combinations the handling capacity of in- and outbound container transports at yard landside depends primarily on the following factors:

- size of the container yard or rather number of corresponding parking lots for trailers,
- capacity of terminal road network,
- traffic volume of truck-trailer combinations serving the seaside,

Fig. 15.7 Stored trailers in the container yard

- utilization of road network and topographic terminal characteristics (like the traveling distance between gate and assigned parking lot in the container yard).

Basically, the dwell time of trucks within the terminal area represents a typical parameter to measure process quality regarding truck related handling capabilities.

15.3.2 Road Network Capacity

According to the German Road and Traffic Research Association the capacity of a road that was built according to the general guidelines for highway design could be determined by the highest traffic volume being able to pass a cross-section (see FGSV (2001)). The traffic volume is defined by the number of vehicles per time unit like one hour. There are several factors that influence road capacity, *viz:*

- number of lanes,
- speed,
- general conditions such as dry or rainy weather and brightness,
- routine of single drivers,
- length of vehicles and ratio of cars to trucks respectively.

Theoretically, one can approach the capacity of one lane by calculating the minimal average gross time gap within a time interval of *e.g.* one hour. Figure 15.8 illustrates the gross time gap as front-to-front distance between two successive vehicles in the traffic flow.

The front-to-rear distance is considered as net time gap. For example, the front of vehicle 1 arrives at the cross-section of the road in Figure 15.8 at 01:00:00 p.m. If the front of the succeeding vehicle 2 arrives at the cross-section at 01:00:03 p.m. the gross time gap is three seconds. In general, the distance or rather time gap between two successive vehicles depends on the reaction time of the driver, the deceleration time of braking, as well as the length and current speed of the car or truck.

Assuming a homogeneous traffic flow with equal deceleration times of braking per vehicle, an average reaction time per driver of 1.8 seconds, an average length per

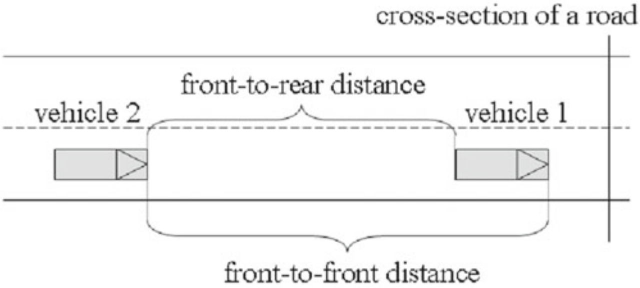

Fig. 15.8 Time gap between two successive vehicles

vehicle of five meters, and a homogeneous driving speed of 90 kilometers per hour, the result of the calculation of the average gross time gap equals two seconds. In terms of one hour or 3,600 seconds respectively, there is a maximum traffic volume of 1,800 vehicles per lane. If a road has several lanes per traveled way it is not allowed to simply multiply the number of 1,800 vehicles per hour with the number of lanes because of interactions between drivers that reduce capacity. Instead, the saturation flow per lane will be a little bit smaller.

Of course, the assumptions above refer to some ideal and convenient conditions including dry weather and daylight. For example, if the share of trucks is higher the average vehicle length will increase resulting in a larger time gap and lower saturation flow. Furthermore, the capacities of single roads determine the capacity of the whole network especially for regional and long-distance travel. In contrast, a road network for local traffic consists of many nodes and short edges. Thus, the capacity of nodes becomes more important to decide the capacity of the whole network.

For example, the road network of the port of Hamburg often has to cope with congestion due to high traffic volumes of container transport. However, the Köhlbrand Bridge is often considered as one of the major bottlenecks of the road network in the port of Hamburg (see Gaffron (2008)). It is located at a central position of the harbor. Normally, the bridge has enough capacity with two lanes per traveled way. But at the end or close to each connecting ramp the customs clearance points reduce the capacity of the road network significantly. In the near future, these bottlenecks will disappear eventually with the reduction or cancelation of the free trade zone. Then, together with increasing traffic volumes, the route via the Köhlbrand Bridge may be responsible for further congestion because it is the only high-capacity connection between the western and eastern part of the harbor. Further bottlenecks may occur at single crossroads or at the terminal gates.

As regards the port of Rotterdam, there have been some severe capacity problems on *Motorway 15* shown in Figure 15.9 (see Konings et al (2009)). It connects the container terminals of the Maasvlakte to the hinterland. Due to high traffic volumes and insufficient capacity the road has been affected by notorious congestion, especially in the years of 2007 and 2008. Thus, trucking companies have started to charge a congestion fee because of the increased travel times leading to income losses. As

Fig. 15.9 *Motorway 15* in the port of Rotterdam (see PoR (2008))

from the year 2010 construction works are planned by public authorities to enhance the capacity of the *Motorway 15* (see Rijkswaterstaat (2008)).

15.4 Measures to Improve the Processing of Trucks at a Seaport Container Terminal

There are several measures that can improve the processing of trucks at SCT. First, the terminal management should integrate organizational changes and partial automation of the truck handling process. Furthermore, the SCT should be involved in the development of a truck guidance system to improve the routing and load factor of trucks for container transport. In addition, the SCT should support other ways to shift the modal split to other transport modes in order to reduce the capacity utilization of roads.

15.4.1 Organizational Changes and Partial Automation of the Process of Truck Handling at Seaport Container Terminals

Figure 15.10 shows an enhanced process of truck handling at a SCT. It starts with sending an advance notice (1) to the terminal operator via EDI. If the terminal operator accepts the advance notice, the forwarding or trucking company is able to book a time slot (2) for truck handling at the SCT. On the way to the SCT the truck arrives at a pre-gate where several characteristics of the vehicle and loaded container are detected automatically (3). Furthermore, there is a check-in procedure to be carried out by the truck driver using *e.g.* a self-service terminal (4). Then, there is a traffic control to dispatch (5) the truck to the terminal according to the booked time slot or free capacities, if the time interval was missed. The dispatching procedure should also consider updated travel times due to current traffic conditions or prognoses.

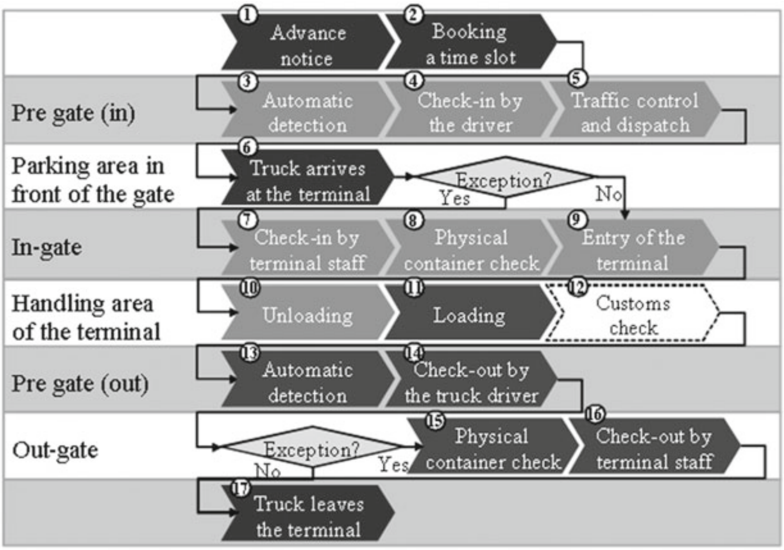

Fig. 15.10 Enhanced process of truck handling

If the truck arrives at the terminal with an ingoing container and no error is found during the automatic detection and self check-in procedure at the pre-gate, it can directly enter the SCT (9)[2]. In case of any exception because of *e.g.* missing data, a damaged container or dangerous goods, a personal check-in by terminal staff (7) may be needed. Thus, the truck driver may park in front of the gate and walk to the interchange before proceeding with the physical container check (8). After having passed the entry of the terminal (9) the truck could be unloaded (10) and loaded (11) again at the terminal's handling area. Subsequently, a customs check (12) may follow, if the SCT is not part of a free port zone. Finally, another automatic detection of container and truck characteristics (13) and a check-out by the driver (14) have to be carried out at the gate before the truck is allowed to leave the terminal (17) with an outgoing box. If an exception occurs during the automatic detection or the self-service check-out procedure a physical container check (15) and check-out by terminal staff (16) is needed before allowing the truck to leave the terminal (17). If the truck wants to leave without any container, no extra checking procedures are needed for the exit.

In general, a high rate of integrated IT systems between trucking companies and SCT is needed because the application of the slot booking system in relation with EDI is essential for using the pre-gate including the automatic detection and self

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[2] Assuming that technology components for automated seal check are in common use in the field of international container transport.

check-in of the truck driver. The benefit of such an automated, IT-supported solution is a faster lead-time for truck handling at the terminal gate. In addition, the SCT could save personnel costs by outsourcing process steps to the forwarding company or rather the truck driver. In contrast, investments in IT hardware and software will rise.

15.4.1.1 Slot Booking Systems

In comparison with airports where airplanes have booked a slot at the terminal for ground and passenger handling, a truck could book a time interval for the check-in, unloading and loading of containers at the SCT (see Giuliano and OBrien (2007)). Thus, a slot booking system could be implemented enabling trucking companies to send their booking data via EDI to the SCT. Reserving a time slot for truck handling already exists widely in industrial companies. Nowadays, several providers for gate IT components are able to improve handling processes and clearly reduce waiting times using time slots for truck handling at their factories or logistics facilities.

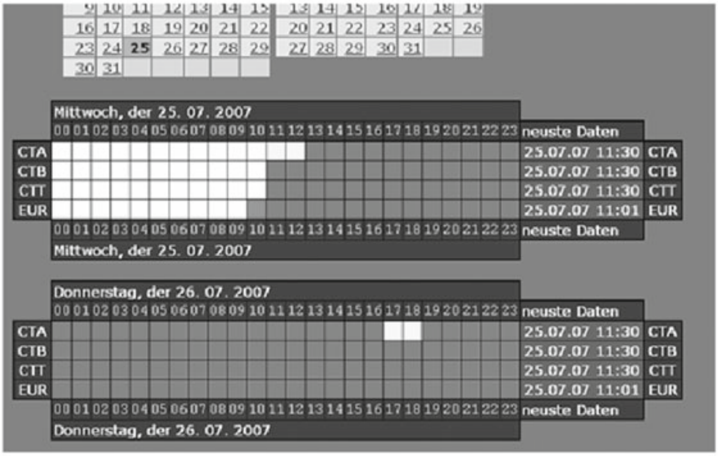

Fig. 15.11 Indication of booked truck handling

Figure 15.11 shows a dummy screenshot for testing purposes of a web application to illustrate the booked truck handling capacity per hour and day of the big four SCT in Hamburg. It is hosted on a web site of an IT-service provider and it is not open to the public. The different possible colors per time slot represent different situations. “Green” shows free capacity, “Yellow” means being short in capacity and red indicates that full capacity is booked. All time slots get a white color, if they are lying in the past, and if no data is available they become grey. In order to get the data the web site is connected to the so-called “truck booking system”, where carriers could reserve a time slot sending a message via EDI. In addition, each terminal has to administrate its capacity per hour and day. As an incentive for punctual arrival, a truck gets a faster service at the SCT's gate.

15.4.1.2 Pre-gates

A container terminal's entry and exit gate operations could easily become a bottleneck creating congestion as traffic volumes continue to rise. In order to provide a better and faster service for truck handling a SCT could implement so-called "pre gates" also known as terminal "automatic gates" or "OCR-gates" that are able to provide a partly automated checking procedure and guided access to the terminal's gate (see Choi et al (2007)).

For example, Figure 15.12a shows the application of *O*ptical *C*haracter *R*ecognition (OCR) technology in the gate areas of the Container Terminal Burchardkai in the port of Hamburg. An OCR portal provides centralized identification, classification and inspection of containerized cargo and equipment entering and exiting a SCT's gate. Usually, the system is able to identify containers, chassis, license plates, and IMDG[3] placards associated with the equipment (see Elovic (2003))[4]. The physical container check to *e.g.* find damages of the container could be done with a camera sending the pictures to a screen at an office workplace. However, if there are any defects or suspicions, a physical container check has to be carried out.

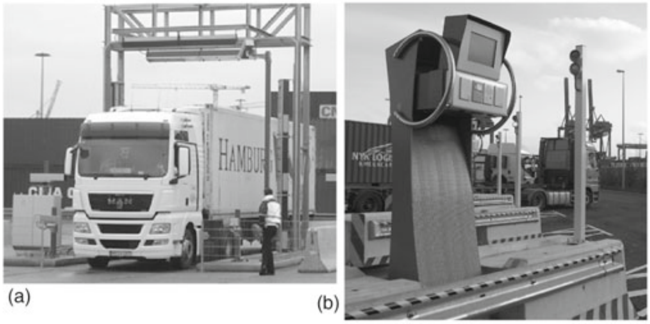

Fig. 15.12 (a) OCR Portal at the in- and out-gate; (b) Service terminal for a self-check-in

After the automatic detection of the vehicle and container characteristics the truck driver could use a self-service terminal as shown in Figure 15.12b to confirm the check-in data that has been detected and sent with the advance notice via EDI. Hence, pre-gates are able to improve the gate process, *i.e.* they may lead to an increase of landside terminal throughput and a reduction of operating costs by container inspection, administration and general security requirements.

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[3] *I*nternational *M*aritime *D*angerous *G*oods.

[4] Implementation of gate and crane OCR systems for container terminal automation and security.

15.4.2 A Truck Guidance System for Seaport Container Terminals

A truck guidance system would be an approach that involves several players such as trucking companies, drivers, terminal operators and a service provider. Essentially, it could contribute to the provision of better information about trucking processes leading to higher load factors of trucks, better control and dispatching of vehicles, as well as the improvement of processes at the SCT.

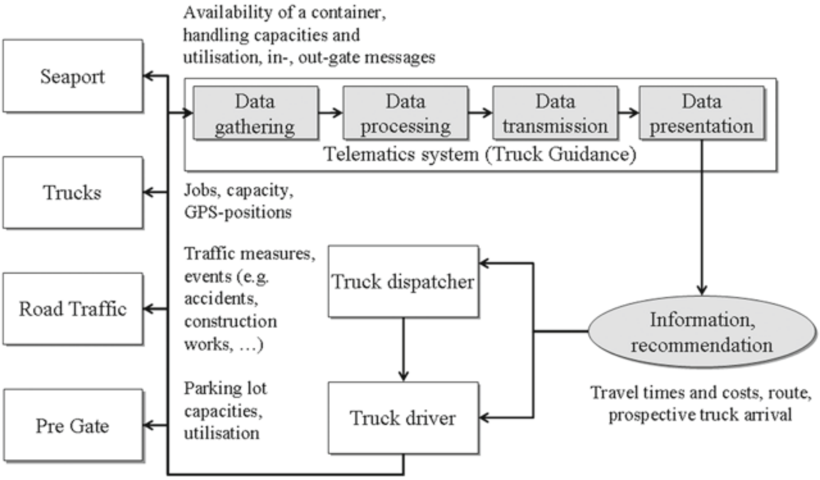

Fig. 15.13 Overview of a truck guidance system

The information provided by the truck guidance system can be considered as a result of telematics services. The word telematics is composed of the two items telecommunication and informatics. Hence, telematics systems combine both communication and information technology to realize a remote action. In general, telematics systems include some local data gathering that will be transmitted over long distances (see Scholz-Reiter (2001)). According to Figure 15.13, a telematics system (functionality) comprises *data gathering*, *processing*, *transmission*, and *presentation* (see Busch et al (2004)). In respect of truck guidance systems for SCT operation the gathered data may include information about the availability of containers, capacities and utilization of truck handling facilities within the process at SCT and pre-gates, as well as messages about single events, like in- and out-gate passage and the current *G*lobal *P*ositioning *S*ystem (GPS) coordinates of a vehicle in the traffic flow. In order to consider additional information about the external road network (*e.g.* current or expected traffic conditions) other measures and tools for data gathering and analysis have to be implemented or integrated in the truck guidance system, respectively. Moreover, information about the scale and utilization of available trucking capacities enables truck dispatchers to decrease the number of necessary tours being associated with a higher average load factor of vehicles. As a result, the (peak) load of public roads and terminal facilities for truck handling is reduced as well.

15.4.3 Shifting Freight to Other Transport Modes

Another measure to improve the conditions of the hinterland connection to road transport is to increase the capacities of other transport modes. For example, the *Motorway 15* connecting the SCT of the Maasvlakte to the hinterland has been a serious bottleneck when container volumes have been very high and continue to grow. Especially, in view of the planned construction works to enhance the road capacity, more severe congestions on *Motorway 15* are expected. Thus, the Port of Rotterdam Authority took the initiative to foster a barge shuttle between the Maasvlakte and a so-called "Container Transferium" (see PoR (2008)) in Rotterdam's immediate hinterland (located in Alblasserdam) in order to decrease traffic volumes on the road as shown in Figure 15.14.

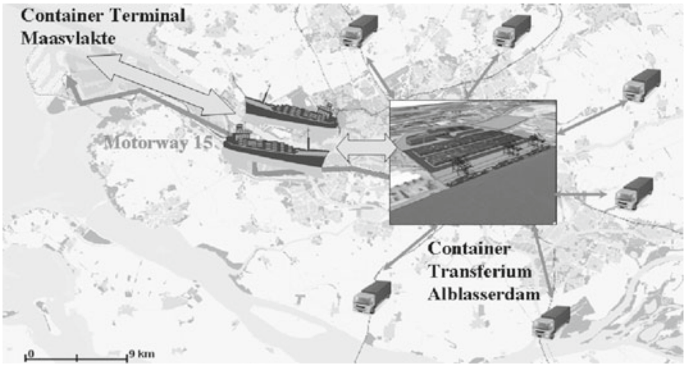

Fig. 15.14 Barge shuttle to discharge road transport (see PoR (2008))

The basic idea behind the Container Transferium is to bundle the container flows, which currently travel by road and shift them to a congestion-free inland waterway connection. The additional handling costs due to the barge shuttle shall be compensated by timesavings and the congestion surcharge that trucking companies have to pay for the transport on *Motorway 15*. All parties in the supply chain are potential clients of the Container Transferium, such as shipping lines, seaport terminals, barge operators, road haulers, freight forwarders, inland terminals, network forwarders and large ship operators.

Following an exploratory phase, the port of Rotterdam brought the market parties together in a consortium to develop a joint business case. Furthermore, the port authority has taken on a leading role when it comes to obtaining support and approval from the national and local authorities. Ultimately, the business community will operate the Container Transferium. The port of Rotterdam will serve as landlord, investing in land and infrastructure in exchange for a competitive rent. Eventually, construction works are planned to start in the year of 2011 and operation is supposed to begin in 2012.

15.5 Conclusion

Due to implications on the overall productivity of a SCT and its high portion of the modal split, road transport is crucial to the performance and competitiveness of a SCT. Nevertheless, the hinterland connection may not be main priority of the SCT's management because its power and possibilities of influence are limited to some extent because usually public authorities are responsible for the condition and especially the capacity of roads outside the terminal. Furthermore, the SCT's most important customers are served at the seaside.

However, SCT operators are able to improve their internal processes concerning the gates and handling areas for trucks. Even if they do not have the power to decide about capacity extensions of the public road network, the management of SCT could improve truck-handling processes through *e.g.* better usage of IT and the installation of pre-gates on private or public ground. As a result, terminal processes may become more efficient leading to cost savings of the terminal operator. Additionally, direct loaders as the final customers of international container transport services may benefit from more reliable hinterland connections and other stakeholders due to e.g. reduced traffic jams on the public road network. More customer satisfaction on this level is also in the interest of ship operators as main logistics service providers within international container transport chains and direct customers of SCTs.

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Chapter 16

Improving Efficiency of Drayage Operations at Seaport Container Terminals Through the Use of an Appointment System

Nathan Huynh and C. Michael Walton

Abstract
Designs of seaport container terminals involve three major infrastructure components: berth, container yard, and gate. In addition, Information Technology (*e.g.* terminal operations system, gate automation, and wireless handhelds) is becoming an integral component of container terminals. Beyond these traditional components, an emerging and potentially effective strategy, terminal planners need to consider to improve gate throughput, is the appointment system. Not only the use of an appointment system by a terminal can facilitate the movement of trucks in and out of the terminal, it can also help the terminal to manage its labor and yard resources. There are challenges to designing an effective appointment system. In this paper, two aspects of the appointment system are examined to provide insight to terminal planners. One parameter of an appointment system is the cap (*i.e.* limit) on the number of trucks that can enter a zone in the yard per time window. Limiting truck arrivals can be beneficial to some extent; however, if the caps are not set properly, it could be detrimental to both the terminal and truckers. The effect of limiting truck arrivals on crane utilization will be explored in this paper. A second aspect of the appointment system that will be examined in this paper is the scheduling rules (individual appointment system versus block appointment system) and their effects on resource utilization and truck turn time in grounded operations.

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16.1 Introduction

A crucial element that often contributes to container terminal congestion is the fluctuating truck arrivals. This unpredictability in demand leads to situations where demand greatly exceeds supply or vice versa. When supply greatly exceeds demand, the terminal is wasting resources, and when demand greatly exceeds supply, truckers lose time and hence money due to the high truck turn time. Truck turn time refers to the time it takes an over-the-road truck (hereafter "road trucks") to complete a transaction such as picking up an import container or dropping off an export container. It is a measure of a terminal's efficiency in receiving and delivering containers. Given that resources (*e.g.* gates, clerks, yard cranes) at a terminal change very little on any given day, excessively long turn time for trucks is often the result of fluctuating truck arrivals. That is, because trucks come to the terminal at their earliest convenience without any prior announcement of their arrivals to the terminal operator, there are times during the day where the number of waiting trucks (demand) greatly exceeds the terminal's resources (supply).

One solution to the fluctuating truck arrivals is to employ an appointment system whereby the terminal operator designates available time windows for containers and subsequently truckers choose one of the available time windows. With an appointment system, the terminal operator could effectively control the truck arrival rates to keep its resources operating at the maximum level while at the same time ensuring timely service to the trucks. Recognizing the potential of this system, legislation in California suggested terminals to adopt the appointment system, among other methods, in an effort to reduce the number of trucks idling (California Assembly Bill 2650); the stated goal of this regulation was to reduce emissions. A subsequent bill (AB 1971) was passed in the summer of 2004 to include truck queuing. Hence, terminals in Los Angeles, Long Beach, and Oakland are subject to a $250 fine for each truck idling or queuing for more than 30 minutes while waiting to enter the terminal gate. The implementation of PierPASS[1] system of extended gate hours and its OffPeak[2] Program has eased the pressure off of Southern California terminals to implement the appointment system. The OffPeak program, which created nighttime and Saturday shifts at the Port of Los Angeles and Port of Long Beach, has eliminated costly bottlenecks in the ports, reduced gridlock on area freeways, and curtailed air pollution from idling traffic. It was reported on July 23, 2008 by PierPASS Inc. that its OffPeak program has diverted more than nine million truck trips from peak daytime traffic since the program's started three years ago. At Deltaport and Vanterm at the Port of Vancouver, every container delivered or picked up from the terminal must have a reservation. Elsewhere, appointment systems are under consideration at the Port of New York/New Jersey.

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[1] "PierPASS is a not-for-profit organization created by marine terminal operators to reduce congestion and improve air quality in and around the Ports of Los Angeles and Long Beach.", see PierPASS Inc. (2010).

[2] "OffPeak is the off-peak hours program created by PierPASS. OffPeak provides an incentive for cargo owners to move cargo at night and on weekends, in order to reduce truck traffic and pollution during peak daytime traffic hours and to alleviate port congestion."

In theory, the appointment system should improve the terminal's productivity and reduce trucks' turn time. However, in practice, because of the lack of specific guidelines for implementing the appointment systems and that each terminal is left to manage their own system, it is not surprising that the lack of structures in the appointment system has led to little time savings for truckers as reported in the work of Giuliano and O'Brien (2007). This problem of inefficiencies due to poor scheduling is analogous to the healthcare industry where variability in both supply and demand in clinics, when left unmanaged, produce crowding, staff overloads, unmet patient needs, and general frustration (see McManus et al (2003)).

It is evident that an understanding of how to schedule trucks to marine terminals is needed to improve the flow of cargo through the supply chain. Given the present situation of soaring fuel costs and rising trucker discontent with port congestion, it becomes increasingly important to consider productivity improvements at ports. This paper explores options to reduce cost and improve service quality at marine container terminals. In particular, it evaluates (1) the effect of capping the truck arrivals on yard crane utilization, and (2) the performance of various simple appointment-scheduling rules under a variety of operating scenarios, and the major factors affecting the performance of scheduling rules. Recognizing that there could be some benefits to capping truck arrivals and conversely consequences of over capping, the central issue with objective (1) involves finding the appropriate level of capping. The central issue with objective (2) is identifying the effectiveness of a scheduling strategy in minimizing idle time of both yard equipment and truckers.

The remainder of this paper is organized as follows. Section 16.2 provides a brief literature review of related studies. Section 16.3 discusses the methodology and framework developed to evaluate scheduling strategies. Section 16.4 outlines the experimental design, followed by a discussion on model validation in Section 16.5. Section 16.6 presents the results and related discussions. Lastly, Section 16.7 concludes the paper with final thoughts.

16.2 Prior Research

There is a vast amount of literature in the area of marine container terminal modeling. With container terminal operation becoming more and more important, an increasingly rapid number of publications on container terminals have appeared in the literature. A comprehensive review of previous work is beyond the scope of this paper. For an excellent review, readers are referred to the works by a team of researchers from Hamburg, Germany who compiled over 300 literature sources tied to container terminal operation as related to operations research (see Stahlbock and Voß (2008); Steenken et al (2004)). The following review discusses published works that pertain to appointment systems employed by marine terminals and appointment systems employed by the healthcare industry which form the basis for this study.

The truck appointment systems were first implemented in California ports in July of 2003 as a result of the *C*alifornia *A*ssembly *B*ill (AB) 2650. Since its first deployment, a few studies have attempted to analyze its benefits. Using actual terminal data, a couple of studies showed that appointment systems can be effective in reducing truck idling/queuing at terminal gates (see Longbotham (2004); Morais and Lord (2006)). Giuliano and O'Brien (2007), on the other hand, found that there is no evidence the appointment system has affected queuing at marine terminal gates. Collectively, these studies show that the appointment system has benefitted some terminals, but certainly not all. The Giuliano and O'Brien study suggested that the lack of improvement stems from either these terminals not embracing the appointment system and simply doing the minimum to avoid paying fines, or they do not know how to schedule the trucks and properly allocate their resources.

A few studies have addressed the effect of the truck appointment system on the drayage firms and supply chain logistics. Huynh and Walton (2008) determined the maximum number of trucks a terminal could allow into its yard and investigated the effect of limiting the truck arrivals on the terminal's truck turn time and yard crane utilization. Namboothiri and Erera (2006) and Namboothiri and Erera (2008) studied how a port's appointment-based access control system affects the management of a fleet of trucks providing container pickup and delivery service (drayage) to a port. Similarly, Ioannou et al (2006) investigated methodologies for the generation of optimum or near optimum time windows for cargo delivery/pickup at marine container terminals taking into account the objectives and constraints of the terminal operator and freight carriers.

While the concept of appointment systems is new to the marine terminal industry, it has been around for quite some time in other industries and has been studied extensively (*e.g.* Healy (1992)). Among these other appointment systems, the one employed by the healthcare industry shares the greatest resemblance to the truck appointment system. The fundamental similarities include randomness in demand, variable service times, multiple operations, substantial no-show rates, and punctuality implications. There are also logistical similarities. In the same way one makes an appointment for a doctor's visit, a trucker must pick one of the available time windows designated by the terminal. The appointment can be made on the day of the visit, and the trucker may cancel or reschedule an appointment. Due to these similarities, this study draws on scheduling strategies developed for the healthcare sector.

This study considers two types of appointment scheduling strategies: (1) *I*ndividual *A*ppointment *S*ystems (IAS), and (2) *B*lock *A*ppointment *S*ystems (BAS). An IAS assigns each truck a different appointment time, whereas a BAS assigns a common appointment time for several truckers. Bailey (1952), Bailey (1954), Welch (1964), and Welch and Bailey (1952) proposed the following IAS: schedule *k* patients to arrive at the start of a session, then schedule patients thereafter at intervals equal to the average service time. That is,

$$\text{set } A_1 = A_2 = \Lambda \quad A_k = 0; \text{ then for } i > k, \text{ set } A_i = A_{i-1} + \mu_t \tag{16.1}$$

where A_i is the appointed time of patient i and μ_t is the average service time.

Welch and Bailey (1952) found that k is optimal at 2. Using their method, one would schedule 2 patients at the start of the day (*e.g.* 8:00 AM). Assuming an average service time of 15 minutes, all subsequent appointments would be scheduled at 15-minute intervals after 8:00 AM (*i.e.* patient 3 at 8:15 AM, patient 4 at 8:30 AM, etc.).

In contrast to the IAS, White and Pike (1964) and Soriano (1996) proposed the BAS: divide the session into k blocks, then schedule $n = N/k$ patients to arrive at the *beginning* of each block. That is,

$$\text{set } A_{in+1} \text{ to } A_{(i+1)n} = iT/k \text{ for } i = 0 \text{ to } (k-1) \tag{16.2}$$

> where T is the session length (in time units) and N is the number of patients per session.

In a marine container terminal setting, the number of blocks could be the number of hours which the terminal gates are opened for operation. Given an average daily number of trucks (*e.g.* 2,000 trucks per day), the terminal would then schedule $n = 2,000/10 = 200$ trucks per hour if the terminal gates are opened for 10 hours a day. Using this method, the terminal ensures a steady and constant flow of truck arrivals at the beginning of each hour.

In equation 16.2, when $i = 0$, A_{in+1} to $A_{(i+1)n} = A_{0\times200+1}$ to $A_{(0+1)\times200} = 0 \times 10\ \text{hours}/10$. So, A_1 to $A_{200} = 0$. That is, the appointment times of the first 200 trucks are 0 (*e.g.* 8:00 AM). When $i = 1, A_{201}$ to $A_{400} = 1$.

That is, the appointment times of the next 200 trucks are 1 (*e.g.* 9:00 AM). Ho and Lau (1992), Klassen and Rohleder (1996), and Harper and Gamlin (2003), among others, tested variations of equations 16.1 and 16.2 under different operational environments and assumptions. They found these strategies to be rather robust. For this reason, this study employs and evaluates these simple yet effective strategies for scheduling trucks to marine container terminals. Additionally, this study evaluates the effect of limiting the number of truck appointments when using BAS on yard crane utilization.

16.3 Methodology and Framework

The basic idea of a truck appointment system is to reduce waiting time of the trucks to the greatest extent possible while maximizing the use of the *R*ubber-*T*ired *G*antry cranes (hereafter RTGs or “yard cranes”). In the container pick up/delivery process, yard cranes are most expensive to operate, much more than the cost of operating the entry and exit gates. Thus, once the yard cranes and labor have been ordered for the day, their efficient use is critical to the terminal operator both in terms of service quality and profitability. Also, in the container pickup process where a container is stacked, the bottleneck is often in the wait for the yard crane to load the container. This is analogous to a health clinic where patients are often delayed while waiting for the physician and not at the check in or check out process. It is noted that this study is more concerned with queuing within the terminal than the queuing outside the terminal. Queuing within the yard is more common at terminals that have grounded operations (as oppose to wheeled operations). In a wheeled operation, containers are kept on street-legal chassis and parked in stalls so that an individual truck driver can position each one; no container handling equipment is needed in a wheeled operation. Terminals without sufficient space to keep all containers on chassis typically use yard cranes to stack containers in a "grounded operation."

Mathematically, the truck appointment system can be described much in the same way it is done in the healthcare industry. The following largely follows the formulation presented by Ho and Lau (1992). Let t_i, b_i, and e_i be, respectively, the crane service time, the time at which the truck arrives at its container location, and the time at which the yard crane has loaded the container onto the truck. If $A_1 = b_1 = 0$, then for $i > 1$, we have

$$b_i = max(A_i, e_{i-1}) \text{ and } e_i = b_i + t_i \tag{16.3}$$

A_i is the appointed time of road truck i. Note that in the case of IAS, each A_i receives a unique appointment time whereas in the case of BAS the appointment time of multiple trucks (*e.g.* A_1 to A_{10}) could be the same. The truck's wait time in the yard is then

$$Q_i = max(0, b_i - A_i) \tag{16.4}$$

The yard crane's idle time (while waiting for truck i to arrive) is

$$R_i = max(0, A_i - e_{i-1}) \tag{16.5}$$

The truck appointment scheduling problem is simply to determine the values of the $A_i's$ to minimize the expected cost, $E(C)$, which is a function of trucks' wait time and yard cranes' idle time:

$$E(C) = \pi \cdot E(Q) + \omega \cdot E(R) \tag{16.6}$$

where is the wait cost of the trucks ($/unit time), and ω is the idle cost of the yard cranes ($/unit time). $E(Q)$ is the expected total wait time of the trucks, and $E(R)$ is the expected total idle time of yard cranes. P and Q are, respectively:

$$Q = \sum_{i=1}^{N} Q_i \text{ and } R = \sum_{i=1}^{N} R_i \tag{16.7}$$

In this study, two simple yet effective scheduling strategies will be evaluated. The first is the IAS as presented in equation 16.1, and the second is the BAS as presented in equation 16.2. These two strategies are selected because they are at the extreme ends of a wide spectrum of possibilities for scheduling trucks. As shown, a pure block appointment system assigns a common appointment time for all the trucks scheduled to be served in a given block. This method is terminal-oriented because it assures the high utilization of the yard cranes at the expense of extremely long waiting times for the patients. An individual appointment system, on the other hand, is truck-oriented because it assures that a yard crane will be available the moment a truck arrives in the yard. The implementation of the appointment system incorporates the following relevant parameters.

Parameters for IAS are as follows:

- The start-time of first appointment.
- The *interval* at which appointments are made.
- Number of trucks at the start of the day. In the Welch-Bailey method this number is 2.
- *Spacing* between individual appointments. Spacing is the added "buffer" time between the end of one appointment and the start of the next. Suppose the average service time is 15 minutes and an appointment begins at 8:00 AM. A spacing of 0 minutes means that the next appointment would be scheduled at 8:15 AM, and a spacing of 5 minutes means that the next appointment would be scheduled at 8:20 AM, and so on.

The spacing parameter is used to account for the number of walk-ins and no-shows. Walk-ins are patients or trucks that show up without appointments and no-shows are those patients or trucks that made appointments, but did not show up. Walk-ins are taken into account by increasing the *spacing* between appointments according to the percentage expected, while for no-shows the *spacing* is decreased.

Parameters for BAS are as follows:

- Number of blocks (*i.e.* k).
- The start-time of each scheduled block (*i.e.* iT/k).
- Number of trucks at 1st, 2nd, 3rd , etc., blocks (*i.e.* n). This parameter can be used to account for the number of walk-ins and no-shows. That is, n should be set lower if the expected number of walk-ins is high, and n should be set higher if the expected number of no-shows is high.

The *M*easure *O*f *E*ffectiveness (MOE) of a scheduling strategy is given by equation 16.6. To determine Q and R, this study relies on a simulation model of a container terminal. Simulation allows for a more realistic representation of the complex terminal operation. In addition, it circumvents the restrictive assumptions of analytical methods: (1) trucks arrive punctually for their appointments; (2) trucks are served in the order they arrive in the yard; and (3) yard crane service times of successive trucks are distributed independently of one another. None of these assumptions correctly describes the random processes that occur at a container terminal, and hence, simulation is needed.

The simulation models developed by the authors to analyze terminal operation are based on the creation of process flow maps of drayage, staff, and equipment and using discrete event simulation software such as *Arena* and *Flexsim* to represent actual timings and activities that occur within each process. Details of the developed simulation model by the authors using *Arena* can be found in their previous work (see Huynh and Walton (2007)). In short, the simulation model was developed for the analysis of truck turn time with respect to crane availability and deployment. It models the precise movements of trucks and yard cranes. Truck movements are modeled by identifying the processes each truck must follow for a particular transaction type and moving the truck through the process via a road network. Transaction types include trucks picking up import containers and/or chassis and trucks dropping off export containers and/or chassis. Trouble transactions are accounted for in the model, as well as double moves. A trouble transaction is a transaction in which the driver encounters documentation issue which requires time to resolve before he is allowed to proceed with the transaction. A double move is an industry term that depicts situations when a trucker drops off an export container at the terminal and then picks up an import container in a single trip. Trucks are modeled to use the shortest paths to their destinations and are modeled to move at different speeds based on a specified distribution. Yard cranes are modeled by identifying the procedure in which they go about the yard providing service to the trucks and moving them accordingly on a crane network. Figure 16.1 illustrates the logic implemented for moving yard cranes. Cranes are also modeled to use the shortest paths to get to their destinations, moving at a specified straight velocity, turning velocity, and acceleration.

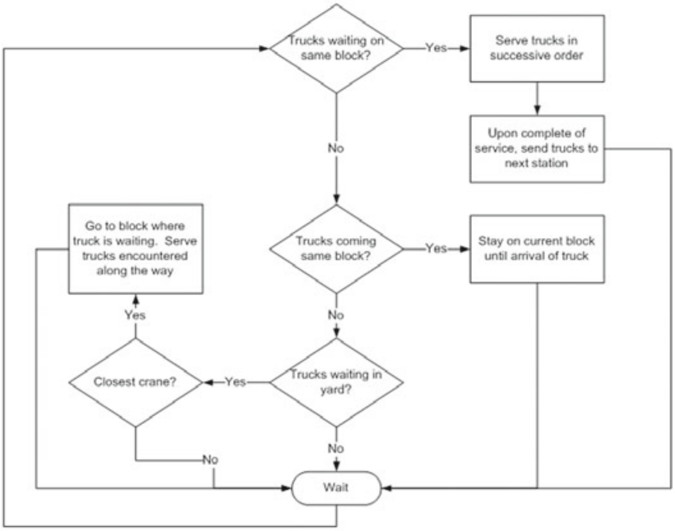

Fig. 16.1 Simulation model logic for yard cranes

Flexsim is emerging as another powerful tool that can be used to model container terminals. Huynh (2009) presented some details concerning the advantages and disadvantages of using *Flexsim* to create simulation models of container terminals. A distinct advantage of *Flexsim* over similar software like *Arena* is that it comes with *Flexsim CT*, a library specifically designed for simulating container terminal operation. The list of *Flexsim CT* objects can be seen in Figure 16.2a.

Many discrete event simulation languages are not particularly well suited for modeling the arrival of demand for an appointment and the actual assignment of an appointment slot (see Isken et al (1999)). As appointment scheduling is very much a database application; this study uses *MS Excel* to generate the appointment schedule. *MS Excel* is chosen over a database application like *MS Access* because both *Arena* and *Flexsim* has built-in functions to import *MS Excel* spreadsheets. A high level view of the truck appointment model is shown in Figure 16.3, and a screen shot of simulation model is shown in Figure 16.2b and c.

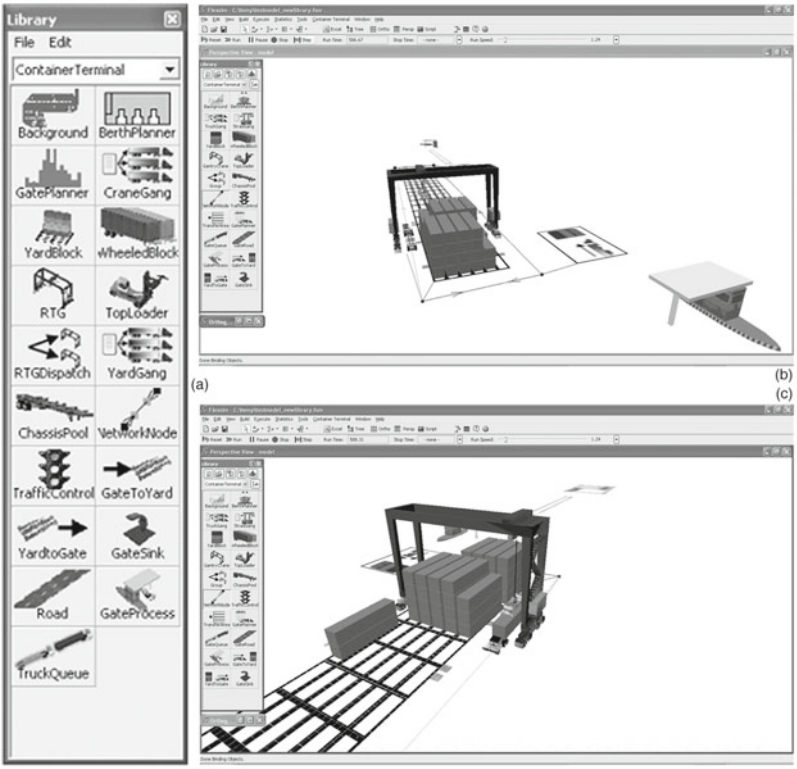

Fig. 16.2 (a) *Flexim* container terminal objects; (b) and (c) Truck appointment model: 3D view

The relevant operational parameters are summarized in Table 16.1. These data were obtained previously for our past studies (see Huynh and Walton (2007); Huynh (2005)) or obtained by the first author during his employment at the Port of Houston. The cranes' deterministic data are the manufacture's specification of the crane's capability in regard to gantry speed and acceleration. The truck's speed is simply the assumed speed limit for trucks on the terminal.

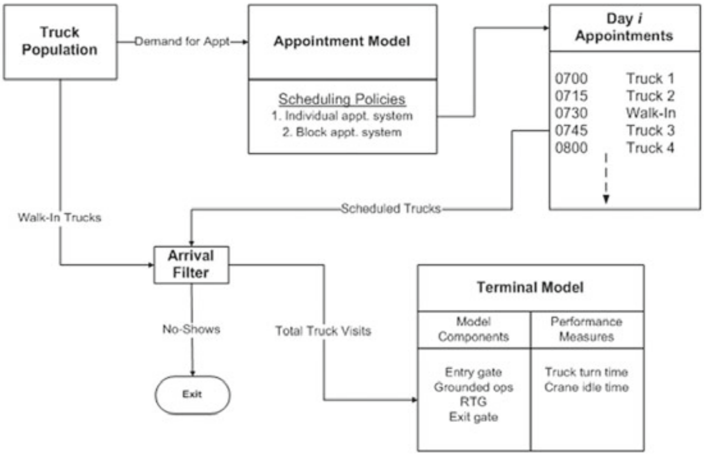

Fig. 16.3 Truck appointment model: process flow

The "pickup travel time" is the time it takes a truck to travel from then entry gate to the yard and from the yard to the exit gate. The processing times are based on actual observed data. They were input into *Arena's Input Analyzer* to obtain the best fit distribution. The developed simulation model used the distributions and associated parameters listed in Table 16.1.

Table 16.1 Simulation model attributes and parameters; notations based on Kelton et al (2007) textbook (*21*)

Truck Parameters	Values
$Max\ speed(m/h)$	30
$Pickup\ travel\ time\ (min)$	TRIA(2, 3, 5)*
Gate Parameters	Values
$Entry\ processing\ (min)$	TRIA(0.5, 1, 4)
$Exit - with\ survey\ of\ container\ (min)$	TRIA(4.5, 6, 28.5)
Road Crane Parameters	Values
$Speed\ (ft/min)$	400
$Acceleration\ \&\ decleration(ft/s^2)$	1.5
Yard Parameters	Values
$Time\ per\ move\ for\ unstacking\ \&\ rehandling\ (min)$	0.26 + LOGN(0.941, 0.519)**

*TRIANGULAR(Min, Mode, Max), **LOGNORMAL(LogMean, LogStd)

It should be noted that for this study, we are not attempting to replicate any specific container terminal. Rather, it is sufficient to have a model that realistically represents terminal operations to serve as a control scenario (without scheduling rules) to which other scenarios (with scheduling rules) can be compared against.

16.4 Experimental Design

To evaluate the effectiveness of different scheduling rules in minimizing the idle time of yard cranes and wait time of trucks, a simple container terminal setup is used. The terminal consists of one entry gate lane dedicated to appointed trucks, a single yard block with import containers, a yard crane assigned to this block to serve appointed trucks, and one exit gate lane dedicated to appointed trucks. It should be noted that in practice not all terminals with appointment systems have dedicated gate lanes for appointed trucks and no terminals make special arrangements for appointed trucks inside the gates. In this study, we adopt to test the scheduling rules on a more forward-looking appointment system. That is to say, a purposeful truck appointment system will have these accommodations.

For the control scenario, a total of 100 appointed trucks per day will arrive at the terminal to pick up import containers, according to the pattern shown in Figure 16.4. Each vertical bar in Figure 16.4 indicates the number of trucks that will arrive during the indicated hourly period on the x-axis. The inter-arrival time between truck arrivals within any single hour is random[3]. As shown, the terminal is set to operate for ten hours, from 07:00 to 17:00 The position of the import containers within the block is random in terms of bay, cell, and tier. When an import container is not on top of a stack, rehandling of containers is accounted for by the simulation model. The control scenario represents the "typical" day in terms of truck arrivals, resource utilization, and service quality. It serves as a benchmark for evaluating the relative benefits of different scheduling rules.

Four sets of experiments are performed to (1) evaluate the performance of two simple appointment-scheduling rules under a variety of operating scenarios, (2) determine the major factors affecting the performance of scheduling rules, and (3) assess the effect of limiting the number of appointments when using BAS.

Experiment 1
The purpose of this experiment is to compare the effectiveness of IAS and BAS against the control scenario under ideal conditions (0% no-shows, 0% late, 0% walk-ins).

Experiment 2
Since it is not possible to test all scenarios due to the numerous possibilities, a few specialized scenarios designed to gain insight into the robustness of IAS under less ideal conditions are analyzed. The parameters for these scenarios are listed below.

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[3] *Flexsim* allows users to specify via the Gate Planner how many trucks will arrive in an hour. It then generates random arrivals such that the total number of truck arrivals matches the user-specified value.

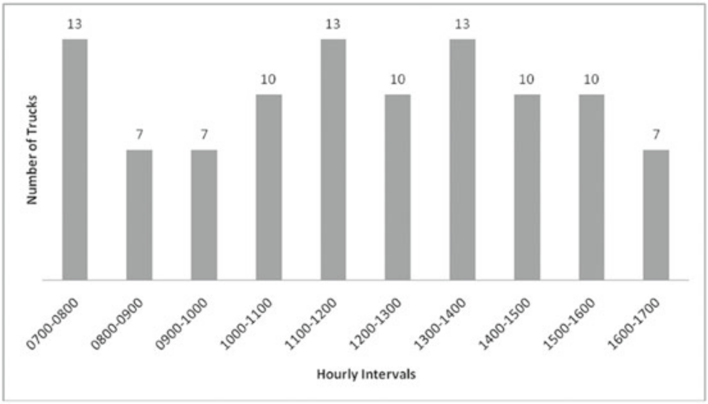

Fig. 16.4 Truck arrival pattern for control scenario

- Scenario 2a: 0% no-shows, 0% late, 15% walk-ins
- Scenario 2b: 0% no-shows, 0% late, 25% walk-ins
- Scenario 2c: 15% no-shows, 0% late, 15% walk-ins
- Scenario 2d: 25% no-shows, 0% late, 25% walk-ins
- Scenario 2e: 15% no-shows, 15% late (15 to 60 minutes), 15% walk-ins

Experiment 3

The same set of scenarios and parameters in *Experiment 2* is repeated here (labeled 3a through 3e), except for the scheduling rule – BAS instead of IAS.

For *Experiments 1*, *2*, and *3*, the following parameters are used:

IAS parameters

- The start-time of first appointment: 0 min
- The interval at which appointments are made: average entry gate processing time (2.5 min)
- Number of trucks at the start of the day: 0
- Spacing between appointments: 2.5 min

BAS parameters

- Number of blocks: 10 (*i.e.* one block for each operating hour)
- The start-time of each scheduled block: 0 min, 60 min, 120 min, 180 min, . . . , 600 min
- n: 10, 10, 10, . . . , 10 (100 total) for *Experiment 1*. The values of n for scenarios 3a, 3b, 3c, 3d, and 3e are 8, 7, 10, 10, and 10, respectively. That is, n for scenario 3a is 8, n for scenario 3b is 7, etc. Note that n can be adjusted to offset the expected no-shows and walk-ins

Note that in our experiments, we assumed that it took 2.5 minutes to serve a truck at the entry gate. Hence, 2.5 minutes was chosen for the interval. Generally speaking, terminal operators should also consider the time it takes for a crane to serve a truck in determining the intervals. However, it is cautioned that terminal operators not severely restrict the number of appointments. *Experiment 4*, discussed below, is designed to examine the impact when a terminal puts a cap (*i.e.* limit) on the number of appointments allowed per hour.

Experiment 4
This set of experiments differs from the previous ones in that it seeks to assess the effect of limiting the number of appointments when using BAS. The data for this set of experiments consist of actual truck arrival data from the Port of Houston on May 29, 2003 (see Huynh and Walton (2008) for details). This experiment examines the effect of smoothing out demand on crane utilization. This involves putting a cap on each block in the yard. Once the number of trucks entered exceeds the cap, the remaining trucks are reassigned to enter in the next hour. For example, if the base data has 16 trucks going into a block at hour 08:00 and if the experiment calls for setting the cap at 10, then the last 6 trucks going into that block at hour 08:00 will be reassigned to enter the block at hour 09:00.

16.5 Model Validation

To evaluate the different scheduling rules, it is essential to have a model that behaves like a real container terminal. The animation and reports/statistics make it easy to verify that the model is working as intended. However, as always, the challenge is in validating the model. Even though the developed model is not a replicate of any specific terminal, it is still possible to validate the model by ensuring the model is producing the expected results from the given input data. That is, the validation process must substantiate that the modeled terminal processes show behaviors and characteristics that are typical of container terminals with RTGs (under assumed operational conditions). Since many of the parameters used in the model are from the Port of Houston's *B*arbours *C*ut *T*erminal (BCT), it is reasonable to expect the model to yield results that reflect the general trends and measures observed at BCT. Through trials for a range of truck demand, the RTG utilization and truck turn time fluctuate in a manner consistent with what the author saw happened at BCT. Knowing what is a reasonable and acceptable change is key in this process, and the author's work experience at the Port of Houston helps tremendously. A few key statistics indicate that the model does have similar operational characteristics as BCT. First, using the control scenario data as input, the model returned about ten container moves per hour for a working RTG. Second, the model yields a utilization rate of about 75% for the RTG. And third, the model produced an average truck turn time of about 35 minutes. The RTG statistics (obtained from thirty simulation runs) are in close to actual values at BCT. The model's truck turn time is lower than the BCT's average of 45 minutes, and it seems reasonable that it is lower given the model has a dedicated gate lane and RTG. Overall, the model exhibits the typical behaviors of an RTG operated terminal and reproduces well the landside terminal activities. As such, the model can be used to study the different scheduling strategies.

16.6 Experimental Results

The results from *Experiment 1* are shown in Figure 16.5. The top graph (16.5a) shows the internal yard turn time of the IAS and BAS compared to the control scenario for thirty simulation runs[4].

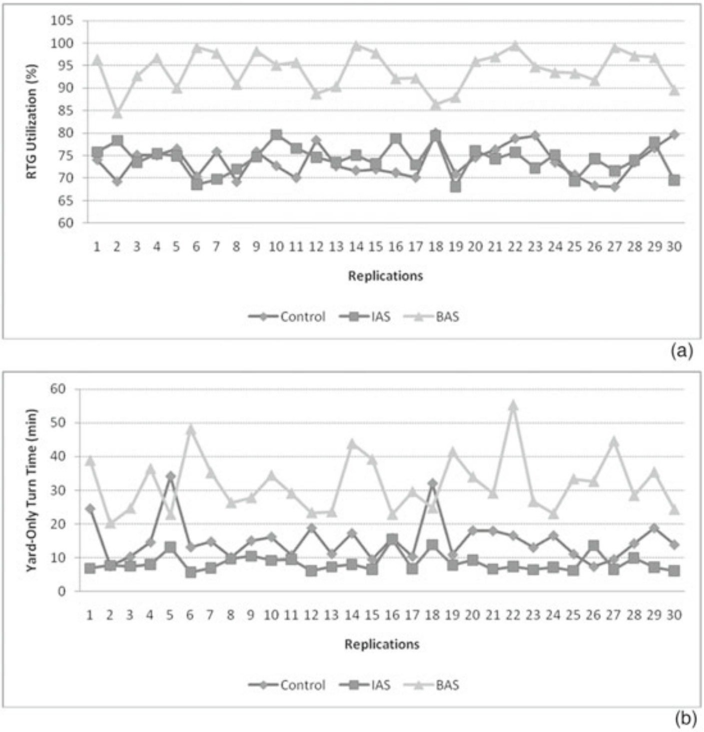

Fig. 16.5 *Experiment 1* results: (a) Yard turn time; (B) RTG utilization

As mentioned in Section 16.3, in the container pickup process where containers are stacked, the truck is frequently delayed while waiting for the yard crane to transfer the import container from the stack to the truck. For this reason and due to the scope

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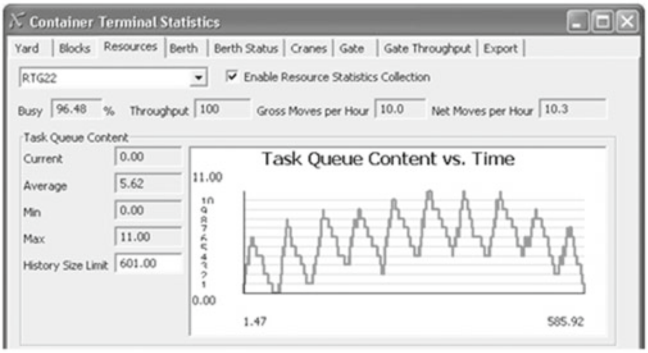
[4] The task of loading an appointment schedule from Excel into *Flexsim* is tedious because it can only be done manually. Hence, experimentation with different schedules is labor intensive. Given that it was not practical to do a large number of simulation runs, thirty was chosen because a sample size of 30 or more is considered to be large enough for the Central Limit Theorem to take effect.

of model, the internal yard turn time is used as the performance measure instead of the overall truck turn time. Note that the internal yard turn time does not include the queuing time at the entry and exit gates. The solution of adding more yard cranes to reduce truck turn time may seem obvious for terminals that stack their containers. However, in practice the high initial investment, plus maintenance and operating costs of these cranes often prohibit terminals from freely buying more. At the Port of Houston for example, due to labor contracts the Port Authority must hire the crane operators for every two cranes.

The results shown in Figure 16.5a corroborate findings from the healthcare industry – the IAS favors the truckers. The IAS yields an average of 8.43 minutes of internal yard turn time versus 15.14 minutes of the control scenario and 31.97 minutes of the BAS. The corresponding standard deviations for these scenarios are: (1) control = 6.22 minutes, (2) IAS = 2.57 minutes, and (3) BAS = 8.63 minutes. So, if a terminal chooses to deploy the IAS, a reduction in internal yard turn time of about 44% can be expected over the do-nothing strategy. Another benefit of the IAS, as shown in Figure 16.5a, is that there is less variability in the internal yard turn time. Trucking companies can better manage their fleet size and schedule when there is less uncertainty in truck turn time.

Figure 16.5b shows that while the IAS is advantageous for truckers, it doesn't fully utilize[5] the RTG, which is an expensive equipment to operate, mainly due to labor cost. The BAS can keep the RTG utilized about 94% of the time compared to 73% by the IAS. To understand how the BAS is effective in keeping the RTG highly utilized, recall that with the BAS a batch of trucks arrive at the yard nearly at the same time on the hour, and hence, there is always a queue of trucks waiting for the RTG. Figure 16.6 shows the ebb and flow of the RTG work queue.



RTG22

☑ Enable Resource Statistics Collection

Busy 96.48 % Throughput 100 Gross Moves per Hour 10.0 Net Moves per Hour 10.3

Task Queue Content

Current 0.00
Average 5.62
Min 0.00
Max 11.00
History Size Limit 601.00

Fig. 16.6 RTG work queue produced by BAS

Figure 16.7a shows the results from *Experiment 2*. Given that the interval is 2.5 minutes and the spacing is also 2.5 minutes, scenarios 2a and 2b are meant to test

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[5] In *Flexsim*, yard crane utilization is defined as the time the crane spent traveling, rehandling, or delivering the container to the truck.

the robustness of the IAS in taking on walk-ins. It makes sense that given none of the appointed trucks miss its appointment, the yard turn time in scenarios 2a and 2b are higher.

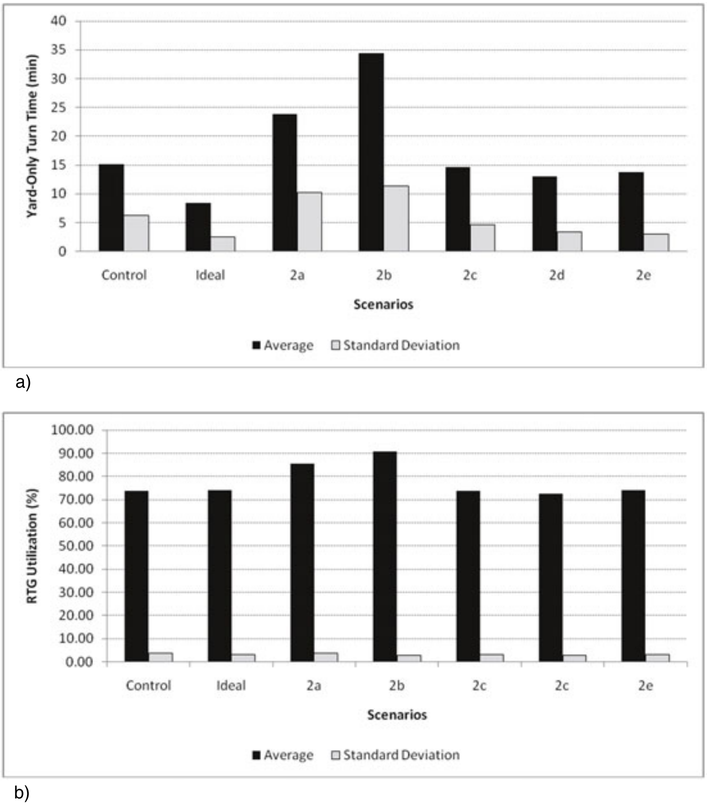

Fig. 16.7 *Experiment 2* results: (a) Yard turn time, (b) RTG utilization

What is striking though is how much higher. With an additional 15% more trucks in scenario 2a, the average yard turn time increased by more than 183% over the ideal scenario (23.89 minute vs. 8.43 minute). In scenarios 2c and 2d, the yard turn times are greatly reduced because the no-shows effectively neutralize the walk-ins. Note that the yard turn times in scenarios 2c and 2d are still higher than the ideal case. The reason is that appointments are no longer evenly spaced apart. Scenario 2e is meant to test the effect of punctuality or lack thereof on the scheduling performance. The yard turn time in 2e is comparable to that of 2c which suggests that the IAS with the given spacing is tolerant to late arrivals (up to 60 minutes). Results from scenarios 2c, 2d, and 2e indicate that a terminal with an IAS is better than one without any scheduling system even in poor operating environments where trucks do not conform to the appointment system.

Figure 16.7b shows that in most cases the RTG utilization under the IAS scenarios is about 73%, except for scenarios 2a and 2b. The reason why these two scenarios resulted in higher utilization is because they had 0% no-shows and a high percentage of walk-ins (15% for scenario 2a and 25% for scenario 2b). In effect, the RTG took on more trucks than it can reasonably handle.

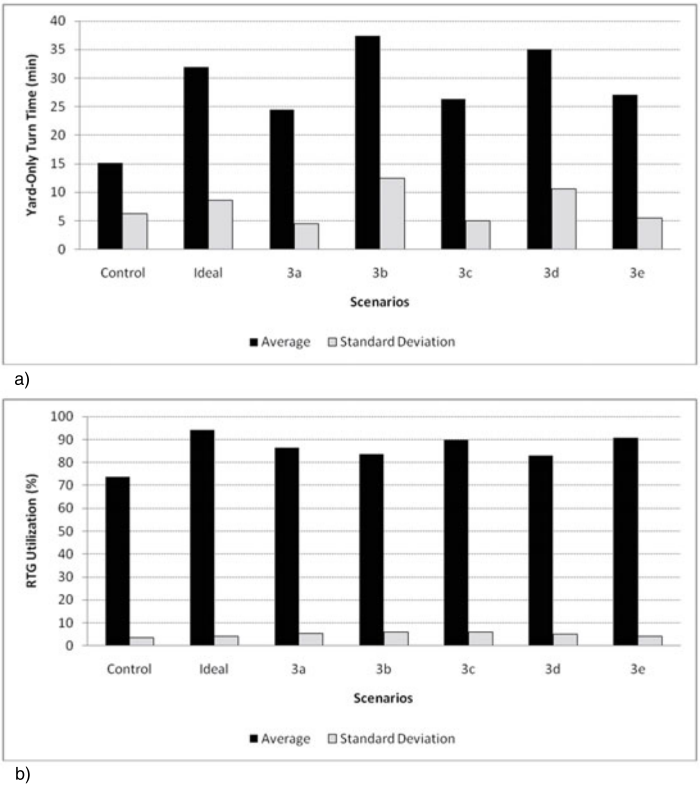

Fig. 16.8 *Experiment 3* results: (a) Yard turn time, (b) RTG utilization

Figure 16.8a shows how the yard turn time fluctuates across scenarios and as n is adjusted to offset the walk-ins and no-shows. The results from scenarios 3a, 3c, and 3e indicate that the BAS is tolerant to the number of walk-ins and no-shows when the percentage is low (15%). This makes sense because the walk-ins effectively randomize the arrival of trucks to the yard, making the ebb and flow of the RTG work queue not as distinct as in the ideal case. The no-shows effectively lower the peaks of the RTG work queue. For these reasons, the yard turn time for scenarios 3a, 3c, and 3e are between the control and ideal scenarios. The results from 3b and 3d in Figure 16.8a indicate that, as the number of walk-ins and no-shows get higher, the yard turn time will get worse. A closer look at the simulation results shows that this is because of the increase in the average number of trucks in the RTG work queue. As with the IAS, the BAS is tolerant to the late arrivals as shown by the results from scenarios 3c and 3e. Figure 16.8b reveals that the BAS is effective in keeping the RTG highly utilized in all scenarios.

Figure 16.9 shows the relationship between crane utilization and cap values. As seen on the graph, if a terminal operator decided to be conservative by limiting the number of appointments when employing the BAS, the crane utilization will decrease. Lowering the cap would counter the main advantage of using BAS: keep the RTGs highly utilized. Hence, the implication of setting the caps too low is that the terminal could be wasting resources.

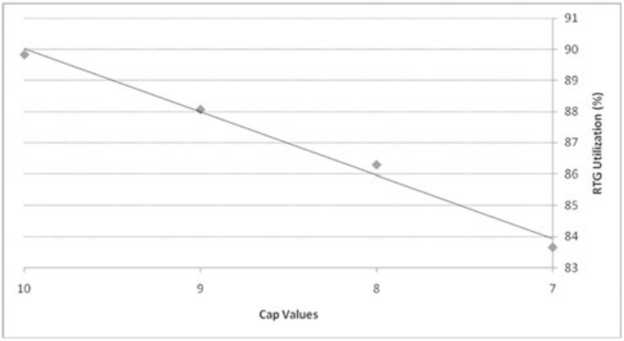

Fig. 16.9 Effect of limiting the number of appointments on crane utilization.

16.7 Conclusions

The results from *Experiment 1* show that there is a clear benefit for a terminal without an appointment system to employ the IAS. Such scheduling system will keep the RTG utilized at about the same rate (74%) as the control scenario while improving the internal yard turn time by about 44%. It is important to note that such improvement will translate to a significant reduction in truck emissions from the reduced idling. While the BAS ensures the RTG is highly utilized, it forces the trucks to wait for much longer compared to the IAS and control scenario (without any scheduling of trucks). Since the high utilization does not translate to higher throughput, it does not make sense for a terminal to employ this scheduling method. Results from *Experiment 2* further confirm the advantages of the IAS over the BAS. With the proper spacing between appointments, the IAS can be effective even when a good portion of trucks are walk-ins, no-shows, or late (up to one hour). It is cautioned however that the IAS is quite sensitive to the number of walk-ins. On a related note, it is surmised that when the parameter *k* (number of trucks at the start of the day) is much greater than zero, it would have a negative effect on the performance of IAS since these waiting trucks are equivalent to walk-ins.

In practice, the truck appointment system works much like the BAS. However, the results from this study (*Experiment 3* and *4*) suggest that both the terminal operator and truckers are better off with an IAS. A terminal that chooses to employ the IAS needs to keep the number of walk-ins to a minimal, unless spacing is greatly increased; the caveat is that the greater the spacing the fewer the number of appointments that can be made. Most terminal operators are pessimistic about getting truckers to change their "walk-in" mentality. The bottom line is if the terminals can prove they have a credible appointment system designed to help drayage operations, it is with great certainty that trucking companies will make every effort to make appointments and be punctual. One such way is to provide additional RTGs to serve trucks with appointments. With additional RTGs and given the same number of appointments, the ratio of the number of trucks needing service to RTGs will be reduced and hence the truck wait time will be reduced. This is true for both IAS and BAS strategies. Last but not least, it is essential that the terminals provide a dedicated gate lane for appointed trucks because the effectiveness of the IAS relies on the gate to provide steady stream of evenly spaced trucks to the yard.

16.8 Benefit of Investigation for Terminal Planning

The foregoing discussion provides some insight into the advantages and disadvantages of different appointment scheduling strategies. Such strategies are valuable to terminal planners who need to consider beyond the traditional methods and technology in an effort to reduce the truck turn time. This is especially true at the present given that drayage operations are now widely recognized as a critical emissions, congestion, and capacity issue for major container ports and rail intermodal terminals. Truck idling in the queues is a contributing source of emissions and noise at terminals. High truck turn time is the result of demand exceeding supply. For terminals that stack their containers, demand is mainly the number of drayage trucks coming to the terminal to pick up or drop off containers. Supply is the number of yard cranes available to serve these drayage trucks. Supply is typically low on high volume vessel days because the majority of the yard cranes are assigned to work the vessel. In such a scenario, drayage drivers must wait for a longer period of time before a yard crane is available to perform the load or unload move. This waiting process can take a considerable amount of time. By using an appointment system, the terminal can facilitate the movement of trucks in and out of the terminal and thus eliminate the unnecessary truck queuing.

This investigation has illustrated the pros and cons of the IAS and BAS as well as the effect of limiting the number of appointments. Terminal planners are encouraged to explore the scheduling strategies explored in this work and conduct their own analysis to determine the suitable parameters for their specific terminals. For example, at automated terminals where there will be less variation in service times at both the gate and yard, the spacing parameter for the IAS could be set lower. The optimal value will require the analyst to test a range of feasible values under typical yard operations and truck arrival patterns and behaviors (*e.g.* no-shows).

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Chapter 17
Data Flow Across the Maritime Value Chain
Case Study on an Integration of Sea Ports and Hinterland Players

Sebastian Jürgens, Roman Grig, Ralf Elbert, and Frank Straube

Abstract
This paper highlights the importance of cross-actor integration on the informational level. It reveals that transparency of data flow along the value chain is a relevant factor for terminal operation. A case study outlined in this paper presents potential improvements through an informational integration of actors within the maritime transport network.

17.1 Background Situation and Formulation of the Problem

The rapid growth of container handling and related port hinterland traffic in recent years has caused all the actors involved to face numerous challenges associated with the proper dimensioning and operation of the network. The actors are faced with several problem areas, which have proved a hurdle to the processing of a growing flow of goods to the hinterland. There is, for example, no constant availability, transparency and speed of information along the maritime transportation chain. Furthermore, the level of standardization of IT interfaces and data communications of the actors involved in the intermodal transportation chain is quite low. One of the

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main causes for the emergence of inefficiencies in capacity utilization along the entire transportation chain has been and still remains the lack of a bilateral or multilateral co-ordination among the actors, which has led the networking of the actors to be characterized by frequent errors and inaccuracies.

Terminal operators register a high rate of rail rebookings for outbound import containers on the loading day, due to flawed co-ordination among the actors, creating unnecessary handling expenses when containers are stored and removed from storage at the terminal. In addition, in export operations, terminals do not have sufficient advance information regarding the cars and container sequences on trains, which prevents effective planning of resources and therefore shorter processing times of trains. Furthermore, inaccurate reporting of changes to vessel sailing lists creates frequent interruption and, accordingly, significant additional cost in the disposition of containers on import trains, as well as it's causing delays in reserves (combined transport train platforms and traction vehicles). Moreover, delays of export trains may cause some cancellation of loading containers and complicate efficient space allocation planning on vessels. In view of the problem areas presented above, it is critical to ensure that the limited resources of the actors are exploited more efficiently.

The actors in the maritime value chain interviewed in course of the Northern Port Conferences[1] identified an improvement of IT networking as a significant area of improvement for the coming years. Due to innovative information and communications technology, the modern maritime value chain and affiliated logistics networks have been changed. The experts interviewed now face the challenge of achieving the use of the available IT systems by all the actors. In the opinion of the experts, the aspect of networking, or the raising of the degree of integration within the transportation network by way of information and communications technologies is becoming increasingly central to the entrepreneurs. It is assumed that continuous alignment between the digital (*e.g.* status messages) and real (*e.g.* events along the transportation chain) world is going to become a critical success factor in the integration of businesses that are part of the transportation network. The objective of this paper is to highlight the importance of cross-actor integration on the informational level along the maritime value chain as an essential factor for the efficiency of processes within sea terminals and hinterland connections. The paper is organized as follows. Section 17.2 gives an overview of the theoretical concept focusing on management of communications and cross-actor information sharing/provision within a network. Section 17.3 describes a case study that focused on advanced actor communication, which was experimentally implemented under real-world conditions within the seaport of Hamburg with leading companies of the maritime value chain. The positive qualitative and quantitative results highlight the importance of the design of com-

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[1] The Northern Port Conference has been organized by DB Schenker and the Berlin Institute of Technology for the leading actors of the maritime network: deep sea carriers, sea-freight forwarders, terminal operators, intermodal operators and rail carriers since 2006. The Conference's participants initiated four working groups with respective focuses on a) data flow, b) long term forecasting, c) extended gate concept, d) operation time in order to facilitate collaborative solutions within these fields of action and research.

munication within seaport terminals. Finally, the paper's conclusion summarizes the perspective of port community systems as an essential element on the informational level of day-to-day operation within logistics networks and their impact on strategic terminal planning.

17.2 Theoretical Concept

The following section discusses the extent to which the network relies on the provision of information throughout the actors involved. The different informational network structures are presented in order to highlight the complexity of cross-actor integration within modern networks. Finally, Port Community Systems are explained as an example for inter-organizational systems for maritime networks.

17.2.1 General Basis

The availability of information in a business network is especially critical for the individual actors when data relevant to competitiveness are involved. The main emphasis, therefore, lies on the degree of information sharing/provision. A question arises: How much information should be transmitted to the partner in order to maintain the vitality of the network and generate gains from efficiency, without suffering any drawbacks? Such drawbacks for businesses may arise if, for example, after receiving detailed information, a competitor is put in a position of being able to make the same customer a better offer. It is for this reason that businesses manage their information more freely or more restrictively depending, among other things, on the respective communications architecture of the network. On the one hand, in bilateral networks with direct *E*lectronic *D*ata *I*nterchange (EDI) a higher degree of control is available over one's own data, allowing also the sharing of sensitive data without the risk of misuse. In these networks the readiness to share one's own data with network partners is more pronounced. On the other hand, there are networks with hub architecture and containing many actors, in which *N*etwork *I*nformation *M*anagement (NIM) is essential and the release of information is handled much more restrictively (see Seidmann and Sundararajan (1998), p. 2ff.). The task of NIM is to assure the provision of information in the long run and to put relevant data at the disposal of the actors.

Relations between the actors of a network are typically shaped at once by cooperative behavior and competition. Therefore, NIM must ensure that a balance between the strategic goals on the one hand and incentives for the actors on the other is reflected in the information flow inside the network. Furthermore, Klein et al (2004) describe the possibility that making information available may strengthen trust among the actors within a network, but that the partners are simultaneously concerned about losing control over the data. This applies especially to *I*nter-

*O*rganizational *S*ystems (IOS), because such systems, by virtue of their original designation, are used mainly for information sharing, and reliable and fast data transfers are decisive for their further existence (see Klein et al (2004), p. 13). An IOS is based on a telecommunication infrastructure which allows the flow of information to be automated between organizations. The main functions of an IOS are: a) information, b) communication, c) transaction, d) cooperation and e) coordination.

17.2.2 Basis with Focus on Maritime Networks

The modern maritime transportation networks require the thorough integration of actors, which is partly enabled by the so-called *P*ort *C*ommunity *S*ystems (PCS). These systems form a so-called network of logistics services, which is understood as an inter-organizational link between providers of logistics services in the literature (see Freichel (1992), p. 12ff.; and Pfohl (2004), p. 12). PCSs are good examples of IOSs, which link two or more independent businesses at the information technology level. In a PCS, the operator is the entity which must build up NIM in order to create a balance between the different partners, which consist in part of net providers and in part of net recipients of information. The determination of the value of certain data and the associated compensation payments to the business making them available are critical for the acceptance of the IOS among the users (see Klein et al (2004), p. 14f.).

Because of the rapid development of information technology in the past years, the entry barriers for businesses have constantly diminished as the functional scale has expanded simultaneously. Srour et al (2008)[2] describe this with the help of two concepts, "exploitation"[3] and "exploration"[4]. Exploitation first and foremost refers to measures geared towards the improvement of process efficiency in the participating businesses, *i.e.* the use of information technology in streamlining routine processes. Deep Sea carriers, forwarding companies, customs, transport operators and the terminal operators are reliant on information from each other to perform their functions (see Long (2009), p. 64). Exploration, on the other hand, describes the attempts of unlocking new areas of application and putting them at the disposal of the users (see Srour et al (2008), p. 3f.).

The architecture of an IOS depends to a great extent on the structure of the network, and primarily on the number of participating users. In case of communication just between two network partners, a bilateral one-to-one architecture presents the simplest solution. This architecture is particularly advantageous for the transmission of critical data, as the information is provided exclusively to the intended recipient. By contrast to this, hub architectures do allow a simple and fast connection to a large number of recipients; however, the aspect of data protection must be paid spe-

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[2] See p. 3f.

[3] In the sense of commercial use.

[4] In the sense of searching and investigation.

cial attention in such systems. For instance, with multi-client communication and transaction platforms[5] separation of individual communicative connections may be effected. This way, businesses are in the position to provide their own information only to selected users, preventing the competition from gaining complete insight into their processes. In this manner, hub architecture can combine the advantages of cost-efficient multiplicity of connections with the security of a bilateral network (see Srour et al (2008), p. 4f.).

A modern PCS represents a multi-client communication and transaction platform that interlinks a large number of bilateral connections, operated by various businesses and organizations that make up the port community (see Rodon and Ramis-Pujol (2006), p. 1). The main characteristic of this infrastructure is the heterogeneity of the individual systems among themselves. All these systems have evolved in parallel in the past and present distinctive interfaces and technical standards. Communication took place in part via an EDI interface or by telephone or fax, but in part also used, and still use, paper documents. In this context, some literature also talks of a Type I PCS (see Srour et al (2008), p. 10f.). These systems are distinguished by a large number of bilateral connections between the members of the port community and allow a simple and fast transmission of messages between two actors. However, there is no intelligent verification of the messages, for example, in terms of plausibility. Figure 17.1 shows a comparison between a PCS in a network of bilateral communicative connections that are not co-ordinated by a higher-order instance.

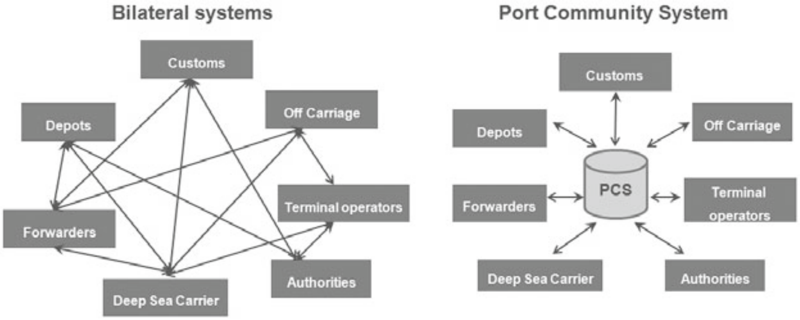

Fig. 17.1 Bilateral communicative connections in comparison to a PCS[6]

The current development of the PCS is summarized under the category of Type II (see Srour et al (2008), p. 10f.). These systems, such as Port Base (formerly Port Infolink) in Rotterdam or the eModal portal in several container terminals in the United States of America, besides the integration of a multiplicity of actors and their bilateral systems, are characterized by additional intelligent monitoring of the

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[5] These platforms are IOSs run by a third operator, which guarantees data's confidentiality through defined rights of access.

[6] The arrows represent information flows between the actors; based on Rodon and Ramis-Pujol (2006), p. 4.

information flows. Thus, the time required to release cargo can be reduced because the necessary information is instantly available to those depending on it (see Long (2009), p. 66).

17.3 Case Study: Piloting of Advanced Actor Communication

The following section summarizes the results of an experimental implementation of cross-actor integration on the informational level. The objective of this pilot is to show the potentials for improvement of terminal processes by implementing an advanced data flow system along the maritime value chain. The findings from this pilot outline that in addition to infra- and suprastructure planning the design and implementation of an appropriate information and communication system is to be considered as an essential element of terminal planning activities.

17.3.1 Introduction

Successful operation of a PCS depends, on the one hand, on the readiness of the actors to make their information available to the network. On the other hand, the optimization potential must be tested by implementing a PCS under real conditions with participating actors. The *Data Flow Optimization Work Group*, established within the framework of the Northern Port Conference under the leadership of *H*amburger *H*afen *L*ogistik *A*G (HHLA) board members, has researched solutions for the optimization of data flows and demonstrated that the timely provision or forwarding of transportation-related information within transportation networks leads to process improvements and an efficient use of resources. At the conclusion of the pilot scheme, leaders of the work group formulated two important recommendations for the participants of the maritime transportation network (see Klotz (2008), p. 8): “The installation of a communication platform for import-related traffic spanning the entire port should have a very high priority. Besides, the awareness among the actors, that timely provision of process- and order-related data has great impact on the efficiency of resource deployment along the chain of transportation, must be reinforced.”

The central thesis during the piloting of the new approaches was that better capacity utilization can be achieved by faster, more accurate and more transparent provision of information. Well-timed information exchange between all actors along the transportation chain can represent the basis for an optimization process for all concerned parties (see Figure 17.2).

In case of import traffic, all the relevant data regarding vessel arrivals must be reported to actors down the line. On the basis of promptly received information, the actors could react accordingly and optimize their operations schedules (such as train, vessel or slot planning). Corrective measures in the nick of time can improve

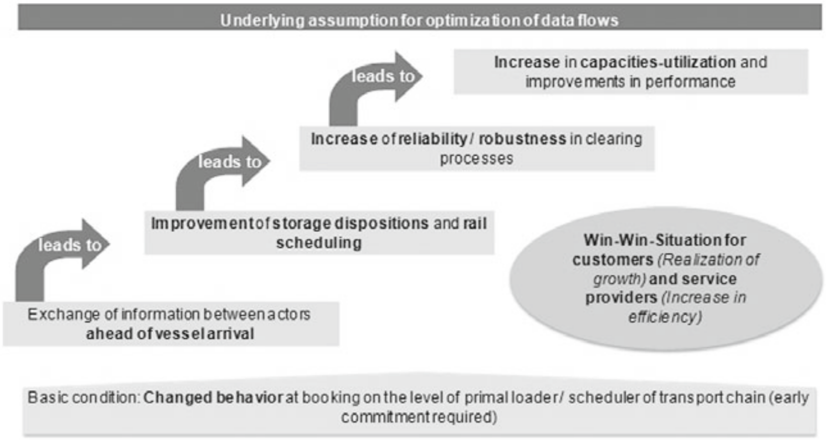

Fig. 17.2 The hypothesis of the pilot scheme at the Port of Hamburg

the reliability of the process, which, in turn, can lead to an increase in efficiency and higher capacity utilization for all the participating actors.

With this basic assumption as the point of departure, a pilot scheme was conceived and carried out involving several notable businesses. During the course of which, it was made sure that all elements of the transportation chain were represented (loaders, deep sea carriers, terminal operators, cargo forwarding agents, intermodal operators, rail transportation companies). The focus was on early pre-reporting of transportation data of import container (see-to-land) with rail-bound off-carriage.

17.3.2 Discussion

The numerous interviews with experts in the run-up to the pilot scheme showed that, for the optimization of port logistics and the process of hinterland transportation, there was a pressing need to unify, *i.e.* use simultaneously, the data of all off-carriage operators, such as cargo forwarding operators and direct loaders in the Merchant's Haulage and deep sea carriers in the Carrier's Haulage. Yet the challenge here lies in the fact that cargo forwarders and deep sea carriers are in direct competition with each other for inter-continental door-to-door traffic, and therefore treat their customer and destination data as very confidential. This lack of transparency of off-carriage data at the moment of unloading of the vessel creates considerable inefficiency for the terminal operator, as well as all the downstream actors such as intermodal operators, rail transportation companies, as well as trucking businesses. Expert surveys have shown that, for the majority of containers at the time of their discharge, terminal operators have no information regarding their off-carriage mode of transportation or the final destination in the hinterland. For this reason, no efficient storage or sorting of the containers can take place on the terminal operator's container stacks.

Within the framework of the Data Flow Work Group, the participating actors together conceived the early issue of transportation orders and a new co-ordination process between terminal operators and the intermodal operator in the event of vessel delays. The participating actors limited the test area to the implementation of the newly conceived data messages, in order to be able to measure the expected effects as accurately as possible. Thus, for example, the HHLA CTA container terminal was selected as the terminal operator, maritime cargo forwarders were represented by Kühne+Nagel and DB Schenker, Hapag Lloyd represented the deep sea carrier, Deichmann Schuhe was involved as the direct loader in the implementation process, the intermodal operators were TFG Transfracht and Polzug Intermodal, and DB Schenker acted as the rail transportation company. For the purposes of limiting the test area, two scheduled services were selected at the HHLA CTA container terminal on the sea side; while on the land side, direct train and hub train systems on certain relations in the hinterland were selected as pilot relations (see Figure 17.3). The effects of the pilot scheme were measured against previously established figures, such as the restacking rate at the terminal and the train processing time on the platform.

Fig. 17.3 Routes of pilot scheme

17.3.3 Results

The off-carriage operators (cargo forwarders, direct loaders and deep sea carrier) agreed on the early provision of information, namely, prior to vessel arrival. Intermodal operators that had been the recipients of the early-release transportation orders were selected as the impartial third party. The received transportation orders were processed by the intermodal operators and forwarded via the rail transportation companies to the terminal operator. The terminal operator received the shipment date of the expected container from the rail transportation company for loading on the train. This information was made available before the arrival of the vessel at the terminal. At this point, the terminal operator was now in the position to introduce a new loopback into its processes: *i.e.* the mirroring of vessel arrival data at the quayside with the rail shipment dates of the containers.

Because of continuous communication between the terminal operator and the deep sea carrier, the former is receiving regular updates regarding the *E*stimated *T*ime of *A*rrival (ETA) of a vessel. In the second step, the terminal operator checks the slot occupancy at the quayside and calculates a new ETA as the case may be and a new *E*stimated *T*ime of *D*eparture (ETD) of a vessel. These two items of information are recorded daily in the so-called sailing list.

The pre-reporting of data, newly conceived in the framework of the work group, now allowed direct alignment of the shipping date of a container by rail on the ETD (qualified in the sailing list). The result of this case study was establishing whether the date of rail shipment of a container was still realistic or whether it could no longer be observed due to the delay of the vessel. If the rail shipment date could realistically be adhered to, the terminal operator was now able to create train-specific stacks of containers in its automated block storage. For the first time ever, several containers were stacked on top of each other for the same train, thus optimizing the train loading in the next step. In case of a negative result of the comparison between the ETD and container shipment date, a return message to the intermodal operators by the terminal operator was conceived, in order to initiate a new container disposition process for the train loading process by the intermodal operators. The intermodal operators received updated details on the ETA and ETD of the expected vessels in sailing list format from the terminal operator, as well as those transportation orders that were marked as critical in the event of a substantial delay of the vessel. On the basis of this information, the intermodal operators were now in the position to carry out the disposition of their trains anew, *i.e.* clear them of unrealistic transportation orders. The updated data were again forwarded to the terminal operator, in order to once more initiate the verification procedure with respect to the ETD and the updated container shipment date by rail (see Figure 17.4).

The pilot scheme produced positive qualitative and quantitative effects. Operational improvements thanks to adjustments in the exchange of data could be clearly felt in the case of the selected actors, for instance:

- parties involved in the transportation benefited from the regularly updated sailing lists
- the need for special trains could be recognized promptly and planned in a better way
- the reliability of the process improved if data of appropriate quality were reported in time

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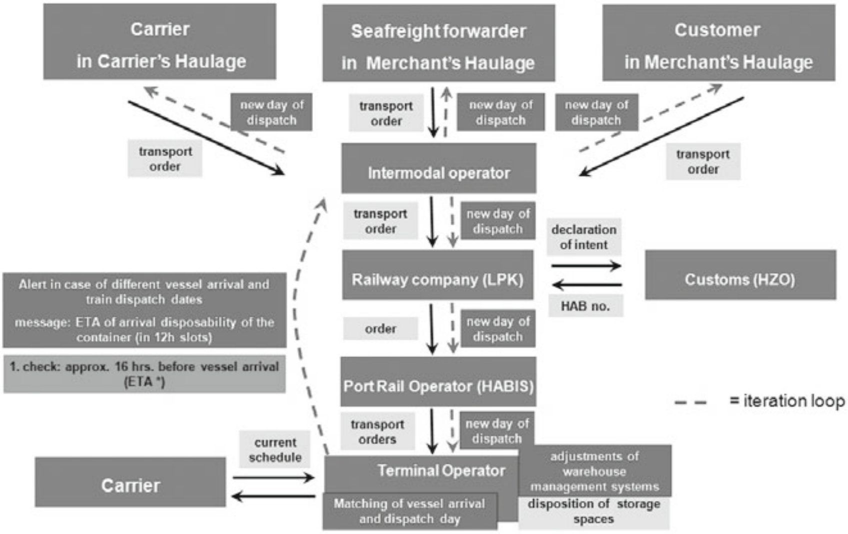
[7] LPK is the name of a resource management system used by DB Schenker for intermodal rail carriage. HZO is a new operating system of “German Customs”. HABIS – Hafenbahn Informationssystem is a resource management system of the port rail operator in Hamburg. HAB – is a code received by “German Customs” after the receiving proving declaration of intent.



* estimated time of arrival

Fig. 17.4 Piloted approaches to the optimization of the data flow (see Jürgens (2009), p. 17)[7]

- customs could commence prompt verification of the orders

Exchange among the actors improved during the pilot scheme: Awareness of other actors within the transportation chain was raised significantly. The effect of the rescheduling of containers for train loading was visible to both the customers and the service providers. In the new setting, the customers of the intermodal operators received timely information regarding delays in the delivery of containers and were in the position to adopt corresponding measures. Certain improvements in the operation were also partially measurable. For example, in the terminal operation, the so-called restacking rate could be reduced (restacking rate = the number of container movements required for accessing and loading a specific container). Also, the train processing times at the terminal station could be reduced for import containers because of the train-specific container stacking in the block storage. The quantitative improvements can be seen in the following illustrations (see Figures 17.5 and 17.6).

A further success of this piloted implementation of optimized data exchange was the identification of areas requiring further action in the maritime transportation network. For example, the actors identified a need for the development and implementation of ETA-messages for the inbound trains with export containers. The participating actors were able to demonstrate the need for the early forwarding of information to the actors in the transportation chain.

In specific terms, this means that, for the optimization along the chain to take hold, transport operators must promptly establish the mode of transportation and destination of the container, so that the actors downstream on the transportation chain are notified in good time and can plan the use of their resources accordingly.

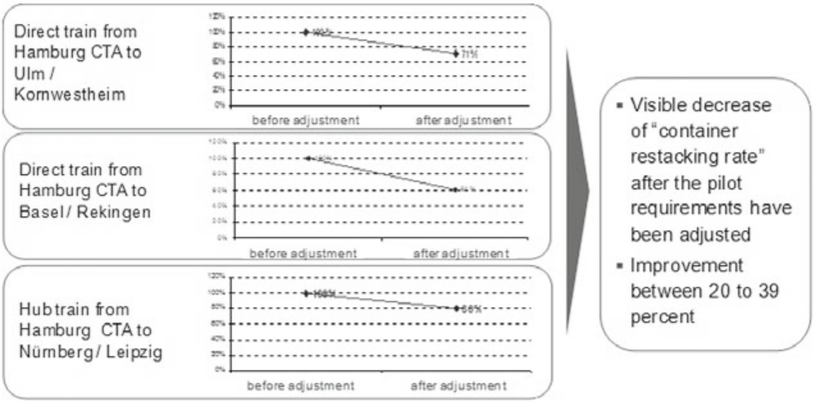


Fig. 17.5 Outcomes of the pilot scheme with a focus on the restacking rate

Furthermore, the pilot scheme produced substantial insights as input in the conception and implementation of a communications platform for import containers for the entire port.

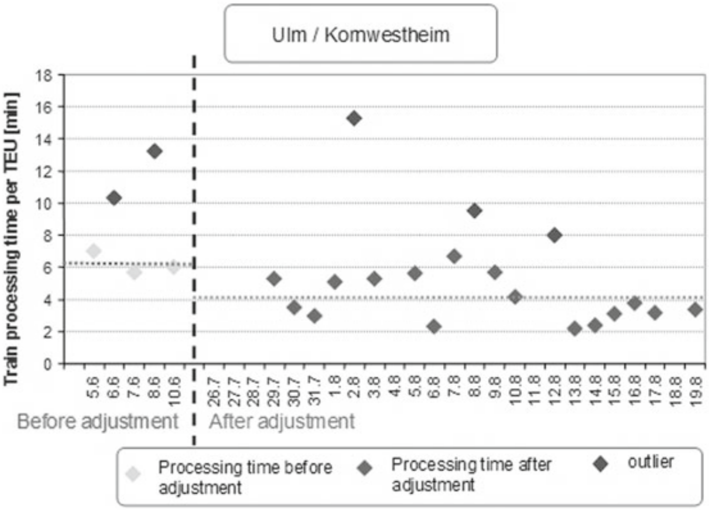


Fig. 17.6 Outcomes of the pilot scheme with a focus on the train processing times on the platform (import container handling)[8]

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[8] The outlier were partly caused by technical failures of the loading equipment (gantry crane at the terminal station).

17.4 Conclusion

The experimental piloting of comprehensive communication among all actors along the maritime value chain has shown that transparency in the data supply chain can unleash considerable potential for the improvement of the performance of the transportation chain. That means, that in order to develop and run an efficient sea terminal, the planners are advised to simultaneously develop an advanced IT-concept for a cross-actor data flow which ensures a high degree of utilization of the installed hardware.

The impact of port community systems on international logistics networks will increase significantly in the coming years, due to increasing demand for reliability and efficiency. Therefore, these systems must continue to ensure that information flows along the transportation chain always precede the physical transport and do not delay it. PCSs have an advantage over the classical approaches to capacity expansion – such as the implementation of infra- and suprastructure – in which they can be adapted to each particular set of factors relatively quickly and cost-effectively. Thus, they present a very flexible instrument for efficiency gains in the maritime transportation networks.

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Chapter 18
The Contribution of the Dry Port Concept to the Extension of Port Life Cycles

Kevin Cullinane and Gordon Wilmsmeier

Abstract
Despite the temporary respite afforded by worldwide recession, limitations on port capacity still plague the container handling industry. At the same time, competitive pressures continue to mount on container ports. In recent years, the dry port concept has increasingly been applied, not only as a vehicle for overcoming capacity problems, but also as a deliberate attempt at expanding or reinforcing the hinterlands of container ports. The objective of this paper is to apply the *Product Life Cycle* to ports and to relate dry port development to the prolongation of the *growth* and/or *maturity phases* of a *Port's Life Cycle*. In doing so, the dry port concept is explained by reference to both the literature and industry examples. The *Product Life Cycle* is then related specifically to container port development, and the prospect of dry ports exerting a positive impact on the *Product Life Cycle* of container ports is evaluated. The paper concludes by identifying the circumstances which are likely to characterize a successful implementation of the dry port concept, such that the desired effect of prolonging a port's *growth* and/or *maturity* phases is achieved.

18.1 Introduction

"*Space is no longer seen as a nested hierarchy moving from "global" to "local". This absurd scale-dependent notion is replaced by the notion that what counts is connectivity*" (see Thrift (2004), p. 59).

It is widely recognized that ever since the dawning of the containerization era in the 1960s, the freight industry has undergone continuous change, growth and development. Past developments have been driven by exponential growth in trade

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volumes and characterized by considerable increases in ship size, rationalization of handling operations in ports and the devolution of port governance.

Ports themselves have responded to this constantly changing environment and, in many ways, have addressed and successfully met the challenges of growing trade flows. The development of both infrastructure to facilitate access to ports and port delivery corridors have invariably, however, lagged behind the response of the ports. In particular, current port infrastructure bottlenecks arise in terms of cargo storage capacity and sea- and landside access. These bottlenecks in some way reflect defects and insufficiencies in the interplay of the economic system and factors that determine port development: transport demand, the structure of trade, transport services, port capacities, etc. Port development can be understood as the consequence (result) of the interaction of three systems: the economic system, the shipping system and the port system as shown in Figure 18.1.

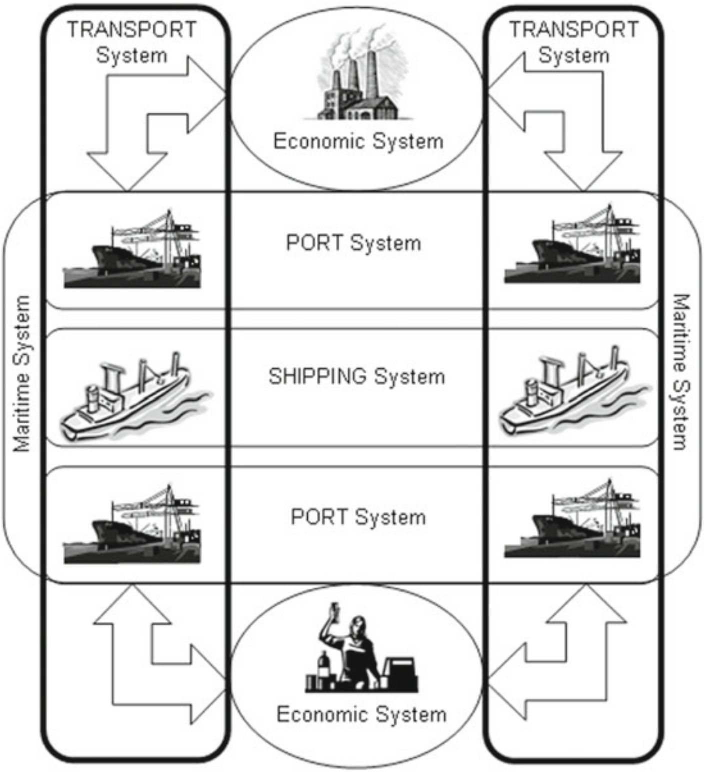

Fig. 18.1 Systems interactions

It is important to recognize, however, that across the world there exists significant diversity in the governance arrangements that characterize and impact upon these three systems and their interaction. As such, no assumptions can be made as to whether decisions or actions are, or need to be, taken by either public or private sector actors within any part of the wider system. In consequence, we eschew attributing responsibility on this basis, preferring instead to focus on ‘the decision maker’.

The economic system, which we consider as exogenous, initiates transport flows and, in consequence, acts on the maritime transport system – both shipping and port services. In general terms, it is the driver for commercial activity and, in particular, for the provision of transport services as a derived demand from the direct commercial demand for internationally traded products. Dynamic changes in the nature of this commercial demand have required structural changes in the transport fleet composition, transport network configurations and the organizational structure of transport services. The maritime system represents a subsystem (although a crucially important one within the context of international trade) of what is a wider multi-dimensionally linked transport system. The maritime system encompasses both shipping and port subsystems which, although always irrevocably interlinked, have become increasingly overlapping and less dichotomous in recent years as shipping companies have diversified into container handling in ports, initially through the promulgation of dedicated terminals and more lately, as newly emergent global terminal operators in their own right.

One basis for distinguishing between the shipping and port subsystems remains, however, the fact that the constituent elements of the latter is composed of physical characteristics in space, while the former comprises mobile elements. The economic and the shipping system together generate and propagate pressure on the port system in the form of ever-evolving specific requirements with respect to infrastructure, superstructure, equipment, efficiency, organization, etc. This prompts a process of time-lagged reaction within the port system to satisfy this changing demand and it is this reactive process which actually constitutes the port development process.

Changes in the port system occur in an almost completely discrete manner, since variations in port infrastructure and superstructure, as well as organizational changes, appear to be rather abrupt and are not implemented or developed in a continuous fashion; investment in the port sector is often characterized as being ‘lumpy’. Moreover, port development is very often dependent upon and determined by the degree to which a specific port in question is embedded within local and regional institutional considerations. Such considerations may or may not be affected by the particular public-private sector mix which prevails in the local and/or regional context, but suffice to say that the workings of the system described herein are generally applicable, irrespective of this mix. Nevertheless, it is certainly the case, for example, that the conditions under which any port system interacts with other subsystems of the wider transport system – in particular, the local port access infrastructure – are very often locally and regionally defined and, therefore, beyond the direct sphere of influence of the port system itself. This is critically important not only to the port but also to the economy it serves, as it is this which ultimately defines the degree of connectivity enjoyed by the economic system which prevails within a port’s hinterland.

Due to the fact that the port system development cycle advances in a discrete manner, its adjustment to the continuous evolution of freight transport demand will inevitably lead to alternating situations of either infrastructural insufficiency and scarcity of supply on the one hand (*i.e.* excess demand), or to a surfeit of port infrastructure (*i.e.* surplus supply). This somewhat natural characteristic of a virtually constant harmonic mismatch of port infrastructure supply and demand can be dramatically exacerbated by failures in local and regional decisions which impact upon the port system. In either case, the effect on the efficiency and performance of a port will be negative.

The major factors determining and reflecting port system development are the: a) infrastructure, b) superstructure and c) institutional and organizational arrangements. Quite apart from the scale economies that may be derived from port system development, there are substantial impacts on port facilities as well as capacities in terms of water depth and handling equipment. A vital challenge that major ports are facing is the provision of sufficient storage space – and many, especially those in traditional locations, close to or even within suburban or urban areas, are in danger of collapsing:

Barnard (2007) states that: "Congestion remains a threat as traffic increases much faster than anticipated. And with expansion projects just getting started after lengthy planning inquiries, it could yet be a case of too little, too late". Similarly, Jaržemskis and Vasiliauskas (2007) point out that: "For historical reasons, most ports in Europe are located in city centers, which demands the effective and safe goods transport with a minimum of environmental strain. Simultaneously, the ports of Europe demand space and facilities for loading, unloading, storage, terminals, etc. in order to ensure the keeping of high quality and growth with the growing traffic and amount of cargo in question."

In consequence, a solution to port system development must be found which takes accounts of the potentially conflicting need for the expansion of ports due to the growth of trade, environmental considerations and community restrictions (not least those imposed by the geography of a port), as well as the evolution of freight transport and logistics more generally towards becoming increasingly embedded within integrated supply chains. One prospective solution that is beginning to emerge more and more often in the relevant literature and provides the raison d'être for this Handbook contribution is the 'dry port' concept. The aim of the contribution, therefore, is to elaborate the implications that the dry port concept may have for the future development of the conventional interpretation of what constitutes a port. Will the implementation of the dry port concept support or supplant the role of the conventional port? In attempting to answer this question, a proven marketing concept will be employed, by applying the *Product* (or rather a '*Port*') *Life Cycle*.

The remainder of the paper is organized as follows: Section 18.2 provides an exposition of the dry port concept, while Section 18.3 outlines the methodology underpinning the analysis undertaken within this paper – *i.e.* the fundamental theory of the *Product Life Cycle* and how it relates to the port context. At this point in the paper, it is posited that the current stage of development of many ports is closely associated with capacity and other problems which constrain future growth. Section 18.4 analyzes whether the widespread implementation of the dry port concept can provide a viable solution to this life cycle problem and conclusions are drawn in Section 18.5.

18.2 The Dry Port Concept

In its original form UNCTAD (1982) defined 'dry ports' as an inland terminal to and from which shipping lines can issue their bill of lading. It was further defined as an inland common user facility that fulfilled a number of traditional port functions, such as temporary storage and customs transit, via various modes of transport with customs clearance and related agencies handling cargoes of different types.

The concept was closely associated with the rapid expansion of containerization and related changes in cargo handling (see UNCTAD (1991)). The UNCTAD report provides an in-depth analysis of the impacts, challenges and benefits of dry ports specifically for landlocked countries.

Since its introduction, the term 'dry port' has been used in various contexts when relating to 'a place inland that fulfils original port functions'. Consequently, and in contrast to its original use, the term 'dry port' has evolved with quite a vague usage; numerous different definitions now appear in the literature and terms like 'inland terminal', 'inland port' or 'multimodal freight center' are often used synonymously or, vice versa, the term 'dry port' is often used as a summary description of what is ostensibly an inland terminal (see Cardebring and Warnecke (1995); UNECE (1998)). Beresford (2009) differentiates between *I*nland *C*ontainer (or '*C*learance') *D*epots (ICD) and 'dry ports'; while both have similar functions, the former is located in coastal countries and the latter in landlocked countries.

Jaržemskis and Vasiliauskas (2007) provide an overview of the different terms for inland terminal facilities. However, the definition applied within this paper and illustrated in Figure 18.2 is that which is originally due to Lévêque and Roso (2002): "A dry port is an inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport."

As also mentioned by UNCTAD (1991), dry ports have the effects of lessening congestion in port and also reducing handling operations in port. If functioning effectively, a dry port connected to a seaport will also alleviate pressure on storage space and thus can redirect the need for the expansion of the port area from the seaward to an inland location.

This paper discusses the functionality of dry ports from a port development point of view and reviews what contribution dry ports make in specific contexts from the perspective of the port development cycle.

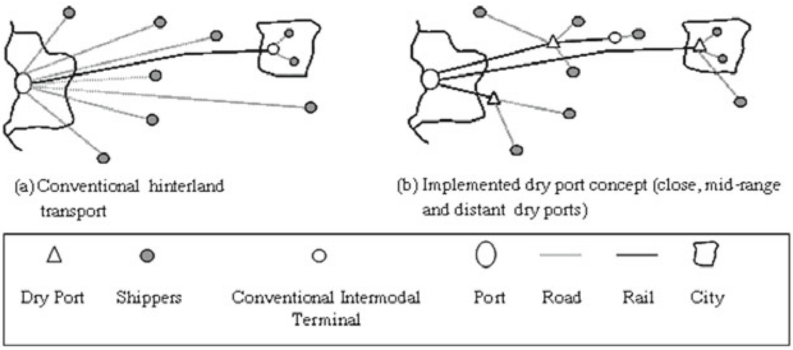

Fig. 18.2 Dry port concept in comparison to conventional hinterland transport; based on Roso et al (2008)

18.3 The Product Life Cycle Concept

This section initially introduces main basics of the *Product Life Cycle* concept being well known from the field of marketing and how the concept relates to the port context (see Section 18.3.1). Subsequently, the life-cycle approach is applied to the port sector in order to solve capacity and other problems which constrain future growth of many ports today (see Section 18.3.2).

18.3.1 Theoretical Exposition

Port development can be defined as a discontinuous, cumulative process, which develops and appears as a series of innovations. Development in this context leads to a structural transformation of the port. To this end, it is necessary to differentiate the term ‘growth’, which occurs without structural change, from the idea of ‘structural transformation’. When growth has reached its limit and further development and the maintenance of a port’s competitiveness is not possible, structural transformation may be called for. This limit to growth is reached when both (a) no further land is available to expand the port’s footprint, or the level of rent payable or development cost for any available land undermines cost-effectiveness and; (b) it is no longer feasible to increase the capacity of a port’s existing footprint by means of technical structural transformations such as the conversion of storage yard technology (*e.g.* HHLA (2008)) or land reclamation (*e.g.* PoR (2010)) and/or organizational innovations which allow for increasing the throughput capacity of a port within its existing footprint.

In certain contexts, we argue that dry ports are a potential response once (or, in economically advantageous circumstances, even before) a port has reached this limit to its growth. Of course, it must be a practically feasible option, with available physical site locations and appropriate means of connectivity to the port itself either already present or potentially implementable. In the final analysis, however, it is the outcome of an economic appraisal of feasible capacity expansion alternatives which informs the ultimate decision taken. As implied above, this may mean that the ‘dry port’ option becomes economically desirable even before some of the more conventional approaches to capacity expansion; for example, where large infrastructure grants are available from public sector authorities and agencies.

In what follows, the effect of growth on ports and the ensuing required spatial structural transformation taking the form of a dry port development is analyzed from a micro-economic perspective through the application of the *Product Life Cycle*. The *Product Life Cycle* assumes that each product has a certain economic life-time which is characterized by a set of common phases. During its economic lifetime, a product is subject to changes in product design, market conditions and conditions of production. Generally, the *Product Life Cycle* suggests that the lifetime of a product, service or branch can be divided into four or five stages as shown in Figure 18.3.

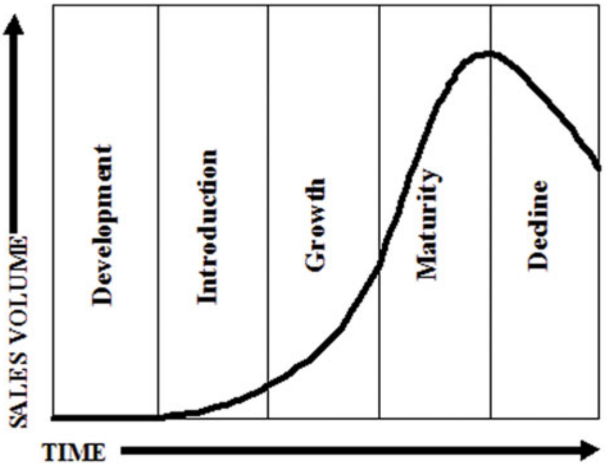

Fig. 18.3 The *Product Life Cycle*; derived from Kotler and Armstrong (2004)

Within the context of the container port sector, a port can be considered to be analogous to a service product in that it can be perceived as exhibiting the same stages in its life-cycle. Ergo, it is then logical to fit the development of the dry port concept into the theory of a *Product Life Cycle* for a port as a strategy for extending the life cycle of that port. Applying the generic *Product Life Cycle* theory to the port context implies a definition of its four/five different stages as follows:

Development and Introduction

The introduction of a port site with related services allows for direct trade with other non-adjacent regions. Services are basic and not standardized as being cargo-based. The port services provided during this stage of a port’s development cycle are commonly from a monopolistic supplier, with human capital as the main factor of production. In addition, the geographic reach of the port's hinterland during this stage of development is typically restricted to the adjacent city.

Exemplifying this stage in the *Product Life Cycle*, Hong Kong's development as a container port began in the late 1960s on the back of a large manufacturing sector, initially with containers carried ad hoc on general cargo vessels. With the continued proliferation of specialized containerships supplanting the carriage of containerships on general cargo vessels, by 1972 Hong Kong had built its first dedicated container terminal. By 1974, Hong Kong possessed four dedicated container terminals. Unusually, but perhaps as a consequence of its entrepreneurial spirit, Hong Kong's container terminals were, and still are, exclusively privately operated. Obviously, at the earliest point in their development, there was significant overcapacity.

Growth

Mirroring the seemingly inevitable long-term growth of international trade, activity in most newly created ports will also inevitably grow from the initial development and introduction stages. As this happens, economies of scale will be realized that will fuel a quickening pace of development. Standardization and process innovation are addressed and implemented, while capital equipment gains in importance over human capital. The geographic reach of the hinterland expands, driven by land infrastructure development and the required port area for storage and port related activities increases.

From its initiation, the capacity of the port of Hong Kong grew significantly throughout the 1970s and 1980s in response to an ever more rapidly increasing demand for it to handle container cargoes. Although during this period, there was burgeoning demand for the handling of transhipment cargoes to and from other parts of Asia, the main source of this growth for the port of Hong Kong was largely gateway traffic, *i.e.* containerized cargoes originating from, or destined for, Hong Kong itself. With the opening up of the Chinese economy in 1989, Hong Kong's manufacturing sector all but disappeared; moving across the border in the form of its significant '*F*oreign *D*irect *I*nvestment' (FDI) in the Pearl River Delta region of southern China. This was to lay the groundwork of the Chinese economic miracle that we recognize today but, even in the early 1990s, provided a significant surge in demand for container handling at the port of Hong Kong. Throughout these growth years, Hong Kong was consistently at the forefront of investing in modern cargo handling equipment and, with the particular prompt of its highly constrained urban environment, was a pioneer in container stacking technology and systems. With the support of the government of Hong Kong, there was also significant investment in land reclamation.

Maturity

Port activity grows at a slower rate, standardization (usually in the form of containerization) becomes fully implemented and competition in the market increases. This latter characteristic is true both internally and externally. As the number of terminals increases within a port, by promoting greater private sector involvement in container handling activities, port authorities will typically move towards stimulating internal competition through the creation of an internal market structure. At the same time and commensurate with greater maturity, external competition increases as the geographic reach of a port's hinterland expands even further and potentially starts to overlap with the hinterlands of other ports. Also during this stage, the port area required for container storage and other port-related activities increases still further, but approaches and sometimes reaches either a physical constraint on further expansion, or possibly a competitive constraint from other activities and land use in areas adjacent to the port. In consequence, investment during the maturity stage of the port development cycle focuses on the rationalization of port services, as well as on process innovations primarily aimed at capacity effects (*e.g.* conversion to more effective storage technologies), particularly as land becomes a scarce commodity and commands premium prices or rents.

In contrast to many geographical contexts, because the development of the port of Hong Kong has always been private sector led, internal competition has always been very intense. In consequence, by the mid-90s competition was intense and efficiency high. However, opportunities for capacity were minimal and the costs of doing so were astronomically high, as were cargo handling fees. In 1995, a major new container port was opened in Yantian, just across the border in the Chinese mainland. By this time, Hong Kong's cargo base rested very firmly with container movements to and from the *P*earl *R*iver *D*elta (PRD) region of Southern China and throughput growth was still continuing apace. In 1997, Hong Kong reverted to the People's Republic of China and the accessibility between Hong Kong and the PRD improved as border controls were relaxed and linking infrastructure improved (see Cullinane (2000)). Nevertheless, the success of Yantian as a new port development was to prove decisive, with more and more containers from the PRD region utilizing the nearer and less complex route via Yantian and other emerging southern China ports, in preference to Hong Kong (see Cullinane et al (2000)). In addition to seeking further improvements in accessibility between Hong Kong and the PRD and reducing cargo handling fees to minimum affordable levels, Hong Kong's terminal operators began investing in container handling facilities in the PRD region in an effort to capture cargoes at source and route that cargo via barge and other river transport through their main terminals in Hong Kong (see Cullinane (2000); Cullinane et al (2004)). This strategy mirrors almost exactly the dry port concept in action, even though, in this case, it is motivated less by the absence of capacity expansion opportunities within Hong Kong (land reclamation almost always remains an option in Hong Kong), but more by the cost of those opportunities and the need to capture the demand for container handling at an earlier point in the supply chain.

Decline

This occurs once the point has been reached when the limitations in feasible rationalization or process innovation in general, investment and access are reached. Port activity reduces. As no further expansion of the port area or no other efficiency gains are possible, the supply of port capacity becomes fixed. As land access becomes increasingly congested, market share is lost to competing ports with overlapping hinterlands and this falling market share will soon manifest itself as declining throughput and sales volume.

In 2000, Hong Kong's port cargo forecasts for the year 2020 were for an annual throughput of 42 million TEUs (see Cullinane et al (2004)). As we arrive at a point in time halfway towards that target date, Hong Kong's throughput in 2009 was 21,040,000 TEUs, a decline of 14.1% over the 2008 figure. Admittedly, this is during a period of worldwide economic recession. However, volume growth in the previous two years had only been 2.0% and 2.1%. All these figures are significantly below the average growth rates for the South China region. As container volumes have grown over the years in the ports of Southern China, at Yantian in particular, so have they attracted ever more numerous port calls from mainline container shipping services. As such, they have undermined Hong Kong's market to such an extent that the port's forecasts of a decade before for a decade ahead of where we now stand are unlikely to come to fruition and growth has stagnated. In the absence of dramatic change – either by way of strategy or circumstances – it would seem that the mighty port of Hong Kong (still one of the world's major players from the perspective of absolute volume of container throughput) may well be standing at the precipice of the decline stage in the *Product Life Cycle*, as a consequence of its lack of competitiveness within the extremely competitive context of its own hinterland.

During the course of any *Product Life Cycle*, key factors will shift and change. For example: production shifts from being labor-intensive to becoming capital-intensive; innovation transfers from being product-based innovation (*e.g.* container transportation) to process innovation (*e.g.* a change in container stacking technology and associated systems in ports); investment is proportionately reduced in R&D and increased in rationalization; production runs shift from small batches (general cargo in the port context) to mass production (containers) and; the market develops from a seller's market to a buyer's market (see Schätzl (1996); Reichart (1999)).

During the transitional process by which a product moves from the development and introduction phase through the growth, maturity and decline phases of its life cycle, the conditions for production and of the market (consumption) will change. One observable consequence of this is that the optimal location for production will typically change from a central (urban) location to more peripheral areas; typically and variously described as any or all of the peri-urban fringe (see Errington (1994)), inter-urban corridors (see Whebella (1969); Davoudi (2003)), brownfield sites (see Alker et al (2000); Yount (2003)), etc. It is this inherent characteristic of a product's evolution through its life cycle which helps explain the way in which the operational scale and scope of freight distribution has become extended over time. Indeed, the four/five standard stages of the *Product Life Cycle* are likely to relate, with a high degree of correlation, to the four stages in 'the extension of the operational scale of freight distribution' identified by Rodrigue (2006) and illustrated in Figure 18.4.

Ports are basically responsive (or reactive) to the demands of their customers (primarily the maritime carriers) and, at a fundamental level, the shipping industry's evolution simultaneously reflects, and has facilitated, the extension of freight distribution operations to a global scale. It is not unreasonable to assert, therefore, that the port life cycle (and where any individual port is positioned within it) is very

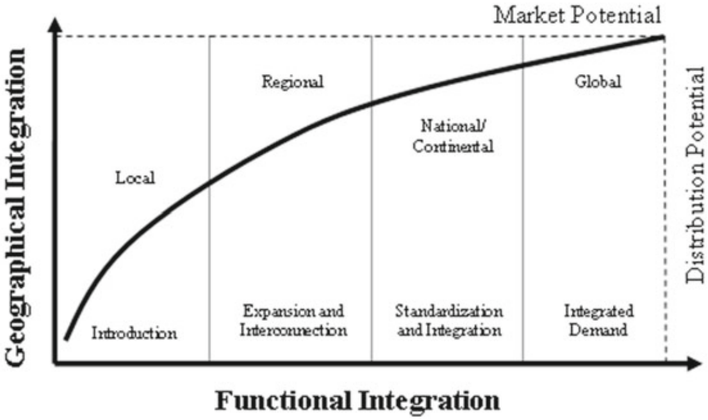

Fig. 18.4 Extension of the operational scale of distribution (see Rodrigue (2006))

much (functionally) dependent upon the level and nature of engagement of the economic system within a port's hinterland with the wider international trade arena. As evidenced in the earlier account of the progress of the port of Hong Kong through all stages of the product development cycle, this is a factor which itself is heavily influenced by the aggregate (or average) stage of *Product Life Cycles* within that economic system as reflected in, and facilitated by, the level of accessibility of that hinterland (see Wang and Cullinane (2008); Cullinane and Wang (2009)) and the subsequent geographical scope of freight distribution.

18.3.2 The Product Life Cycle Applied to Ports

As outlined in the previous section, patterns of port development derive from the spatial locus of influence of ports. Technologies and (re)organization enable the drivers for change since it is these which lead to the rise of new, and fall of old, products (services), processes and locations. At the time of their initiation, ports operate at a local level. They then extend their influence on the seaward side to the regional and later to the national and continental level. The final stage is the global level. Because of the latest developments in the structure of maritime networks, in this final stage, one also has to differentiate between hub and gateway ports that operate at the global level. In respect of this, it is interesting to note that while the expansion of reach on the maritime side of a port's operational environment is clearly recognized and relatively widely analyzed, the process of a port's spatial development of its hinterland (other than simply the fact of its expansion) has received considerably less attention.

These port development cycles vary in their duration; their length depends significantly upon the external pressure emanating from the economic and maritime systems and the degree of effectiveness and efficiency of the port organization and the institutional framework within which it works to respond to this pressure. Storper (1997) avows that port development is based on three pillars: technology, organization and territory, with intense interaction between the three. He argues that the development of the port organization is influenced by technological development and the spatial development context and that it is this which leads to the realization of organizational, communication and learning processes that produce a competitive advantage for a port.

Certain activities or actions can lead to changes or shifts in the normal port development curve. Not only can one development cycle be substituted by an alternative prior to the full cycle having completed, but also phases within the port development cycle and, therefore, the overall port development cycle itself can be extended in their duration through technological or organizational changes or, more specifically, through the extension of the phase where increasing standardization takes place (see Chase-Dunn (1981)). This renewal of the port development cycle is driven internally by process (discontinuous change in the factors of production) and product (discontinuous change in service offer) innovations.

Obviously, the development and introduction phases of the seaport life cycle are partly concerned with the selection of the location for the port in question and the establishment of that port as a competitive player over a certain initial hinterland and within a certain port range. Although these are very important issues that will impact upon the later phases in the life cycle of a port, the focus of this work rests with the ensuing three phases of port development and movement through its life cycle, concentrating in particular on the challenges which arise during the maturity phase. The primary area where examples of such challenges occur most frequently is, therefore, in the European seaport sector.

Continuing growth in container traffic and changes in the nature of container shipping operations has led to increased pressure on ports in a number of ways. The deployment of ever-larger containerships has resulted in increased draft requirements to allow better access from the sea (see Cullinane and Khanna (1999); Cullinane and Khanna (2000); Imai et al (2006)). Growing traffic levels have also led to significant pressure on investment requirements for landside and hinterland access. In addition, growth has required process innovation and the rationalization of container handling, as well as maximizing the use of storage areas in ports; aspects that have now attained a high level of sophistication, as illustrated in work such as that by Cordeau et al (2001), Imai et al (2001), Zhang et al (2002), Kim and Moon (2003), Park and Kim (2003), Vis and Koster (2003), Christiansen et al (2004), Guan and Cheung (2004), Hansen et al (2008).

Irrespective of whatever continuous improvements to container handling and storage are implemented, there are inevitable limits to the efficiency gains that can accrue from deploying new technology and rationalizing operations. Ultimately, therefore, continued growth in container traffic leads to a lack of space at seaport terminals and growing congestion on the access routes that serve them. Port management will be very much aware that underinvestment and any persistent lack of capacity will mean that, where a choice exists, customers will eventually divert their business to competitor ports, leading to an enduring negative impact on port development and competitiveness. In any case, even solely in terms of opportunity cost, a significant loss in container traffic will result and this possibility puts pressure on ports to invest in infrastructure and superstructure. However, such investments constitute a significant financial burden and lead to the requirement for further expansion of other port facilities.

Providing the ultimate solution to port capacity problems, in recent years proposals for new ports and terminals have become a familiar part of the maritime landscape (see Rytkönen (1999)). Due to a lack of available sources of finance, legislative barriers, restricted land availability and other difficulties, the actual development of new ports or terminals has thus far been rather slow and sparse, even though it would seem inevitable that brand new port capacity will need to be built at some point in the future to take account of predicted changes in shipping and transport technology.

The major European seaports now find themselves having fluently progressed from the growth to maturity stages of the *Product Life Cycle*. In accordance with the *Product Life Cycle* theory, therefore, a large proportion of the European port sector now faces inevitable and imminent decline. If this is indeed the case, the concern of European port management, in particular, is to determine how to effectively counteract this expected decline.

According to Schätzl (1996), spatial development should be considered at this stage of the life cycle. He states that the requirements for an optimal location will change as the standardization of processes, competition and price wars, as well as the capital intensity of tangible assets, all increase. Schätzl (1996) concludes that these new economic characteristics influence or even force a "Standortspaltung" (location splitting) and the establishment of a subsidiary in the hinterland. Ultimately, port capacity problems manifest themselves in the form of these economic characteristics. Equally, however, such characteristics may prompt a port to opt for a dry port solution at some time prior to experiencing capacity problems. In either case, this hypothesis suggests that in order to extend either the growth or maturity phase of the traditional seaport life cycle, the adoption of a "Standortspaltung" strategy towards the landside or hinterland of a port provides a potential solution to the problem of avoiding inevitable decline. A dry port would thus seem to be one response to overcoming the constraints faced in the traditional location of a port and is infinitely preferable to the complete relocation of the port as a whole.

A strategy of "Standortspaltung" can only be successful, however, if the transport link between the port and its subsidiary locations is not only economically attractive, but also of significant quality such that it allows for a sufficient level of throughput. The successful promotion of intermodal transport becomes, therefore, the most critical action in order to accomplish a successful and sustainable extension of a *Port's Life-Cycle* by applying a dry port strategy.

When considering a dry port strategy it is necessary to define the port system. Unfortunately, the concept of a port system is rather vaguely defined from a geographic perspective. In what follows, therefore, we regard the port system as corresponding to a single port region within which port activities substantially impact upon the economic structure (*e.g.* employment) and the hinterland of this port system as the area from which captive cargo is sourced. Thus, with the development of a dry port, the port system splits its activities in a spatially discontinuous manner, with the aim of altering, reorganizing and bundling related cargo flows. Not only will this increase market dominance in the hinterland, from a port's perspective it will also alleviate growth restrictions in the coastal location. An additional benefit that derives from the dry port concept in comparison to conventional intermodal shuttles is basically due to the possibility of customs clearance that accelerates the interface with the shippers. As Roso et al (2008) point out, "The main reason for the seaport to engage with a distant dry port is that a wider hinterland can be secured by offering shippers low cost and high quality services."

18.4 Dry Port – a Solution?

If the conclusion is reached that a dry port could become a necessary subsidiary location in a seaport's hinterland in order to maintain the competitiveness of a port, a new issue is then raised: How should the implementation of the dry port concept be organized to ensure it is successful? When considering the implementation of a dry port, the starting point is the identification of a site that could possibly become a dry port. Harrison (2008) suggests that: "This site may currently operate as an industrial park, intermodal hub, or river port, or might not operate commercially but display logistics potential."

Roso et al (2008) define three types of 'dry ports', considering distance between the seaport and the dry port location as a key differentiator. They distinguish between distant, mid-range and close dry ports (see Figure 18.2). A distant dry port is the most conventional of the three and has the longest history (see UNCTAD (1991)). The main reason for implementing this form of dry port is simply that the distance and the size of the flow make rail viable from a strict cost perspective (see Wiegmans et al (1999)).

Roso et al (2008) also argue that by combining all of the three types of dry ports they define, a port and its surrounding city location can be relieved of all road connections outside the city area. This assumption might be theoretically true, but in the real world would require a very strong policy framework to be implemented. They also argue that the dry port concept goes beyond the conventional use of railway shuttles for connecting a seaport. Roso et al (2008) refer to this as 'being strategically and consciously implemented jointly by several actors' and going well 'beyond the common practice in the transport industry'. This may be overly simplistic however, since a rail connection is only the facilitator of the dry port and, in whatever circumstances exist, it remains a rail service. Much more important would be the question of the ideal operating scheme for such a service, since a dry port must allow for non-discriminatory access.

The competitiveness of intermodal transport, particularly road-rail combinations, depends on both geographical context and the demography of the area under study.

In general terms, rail is generally competitive in price-quality terms at distances above 500 km (see van Klink and van den Berg (1998)). According to Roso et al (2008) a mid-range dry port[1] is located at a distance from its associated seaport which would normally militate against the use of rail, with general coverage achieved primarily by road transport. However, with the mid-range dry port serving as a consolidation point for different rail services, a rail link to the port becomes viable. The efficiency of such a configuration is further enhanced by the fact that administrative procedures and certain technical equipment that are specific to using sea transport (for example X-ray scanners needed for security and customs inspections) are just needed in one terminal. Roso et al (2008) elaborate further by stating that: “The high frequency achieved by consolidating flows together with the relatively short distance facilitates loading of containers for one container vessel in dedicated trains. Hence, the dry port can serve as a buffer relieving the seaport’s stacking areas. If this is a severe constraint, shippers with comparable distance to the seaport and the dry port can then be directed to the dry port if it is made cost neutral to them. In other dimensions, the benefits are similar to those of a distant dry port.” Hence, a mid-range dry port would address the problem of storage space within seaports approaching full capacity utilization.

Finally, there is the close dry port option. The fundamental aim of a close dry port is to ease the traffic congestion in the urban areas around a seaport. This is achieved through the use of the close dry port for consolidating shipments made by road transport to and from shippers outside the city area and then offering a rail shuttle service to the coastal port. In so doing, this relieves congestion in both city streets and at port gates. According to Roso et al (2008), “Compared to the other types of dry ports, a close dry port offers larger possibilities for buffering containers and even loading them on the rail shuttle in sequence to synchronize with the loading of a ship in the port. This obviously requires a very reliable rail service to avoid the risk of increased dwell times of container vessels and then a dedicated track is probably required initially.” In most of Europe’s urbanized port areas, however, the potential for developing new on-dock rail infrastructure is rather limited. The consequential reliance on other means of transfer from the nearest rail access point may undermine the benefits of this option.

Roso (2007) comes to the conclusion that the implementation of dry ports is part of the solution to overcoming port congestion and improving hinterland access. From her analysis she concludes that port-related traffic in areas close to the port can be reduced and that the shift from road to rail for part of the transport leg to the port can reduce CO_2 emissions. Roso (2007) further states that the quality of access to a dry port and the quality of the road-rail interface also determines the performance of the dry port.

It is certainly the case that there will be specific geographical contexts within which the application of the dry port concept will have any or all of the desired effects of overcoming a port’s capacity limitations, improving access to a port’s ex-

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[1] Within the context of the paper by Roso et al (2008), a close dry port is deemed to be within a distance of 50 km, a mid-range dry port is located between 50 km and 500 km and a distant dry port at over 500 km.

isting hinterland and expanding the customer base through hinterland expansion. Wider socio-economic benefits in terms of reduced road congestion and less environmental damage may also accrue. It is also certainly the case that the level of performance of a dry port will be a key factor influencing the scale of benefits derived, particularly from the microeconomic perspective of the port which is evaluating the instigation of the dry port concept. Ultimately, however, such a strategic decision has to be justified on economic grounds and estimates of the extent to which these characteristics will manifest themselves will exert considerable influence over the outcome of an economic evaluation of such a proposed initiative. Depending upon economic, geographic and other circumstances, there will be instances where the economics justify such a decision. There will also be cases where external incentives for taking such decisions need to be provided by policy makers in the wider interest of society. Whilst these may have the desired policy impact, there will invariably be cases, however, where implementing the dry port concept remains economically infeasible. In summary, therefore, it can be stated that the potential for the dry port concept to extend the *Product Life Cycle* of a port will fundamentally depend upon the economics of the particular situation; such a strategy may be justified purely and simply from a private profit perspective, on some occasions the receipt of some form of subsidy may be required and in some cases, no realistic level of subsidy will prompt the adoption of the concept.

18.5 Conclusion

A dry port only makes sense if it is able to support a future port system (*e.g.* an n-terminal hub) without increasing the relative amount of traffic per unit. To achieve success in the implementation of the dry port concept, it is necessary to determine what purpose the dry port should serve. For the purposes of establishing government policy on dry ports at either a national or regional level, the most critical question that needs to be addressed is whether the establishment of a dry port represents merely a protectionist measure to maintain an old seaport that is no longer viable without that dry port or should it be designed with the intention of becoming an integral element of a functional future port system?

This is not to say, however, that such policies form any sort of necessary prerequisite for the commercial adoption of the dry port concept. There are, in fact, several real-world examples where the dry port concept has been instigated by ports as a purely commercial undertaking, quite often as part of a joint venture with other entities that may reap benefits from such an initiative. For example, the **Terminal Marítima de Zaragoza** was opened in 2009 and is located approximately halfway between Madrid and the port of Barcelona. As such, it serves the industrial region in the north-east of Spain. With annual throughput of roughly 20–30,000 TEU, this dry port is linked to the port of Barcelona by 6–8 rail services per week. The terminal is owned by the company TM Zaragoza, which at the time of writing has a shareholding of 56% ZAL Mercazaragoza (a long-established logistics park at the site), 21% by the port of Barcelona and 20% by the region of Aragon.

Focussing on the idea of some centralized authority establishing a dry port as a protectionist measure, a vital precursor is the decision about which seaports should be supported by a dry port. Is there inter-port competition within the country or region, or even between neighboring countries? Should a dry port serve several seaports or just one? How does the dry port need to be established and organized and how should it be laid out in order to ensure it becomes a success? There will probably be conflicts at different regional levels. If a dry port should support only one or a few selected seaports, what happens to the cities that will face a continuing decline in their seaports as a consequence? How should the local economic problems that arise be dealt with?

Similarly, the **Virginia Inland Port** was established in 1989. It is located at Front Royal, 350 km inland from the major U.S. port of Hampton Roads, and offers rail services to all three of the Virginia Port Authority's marine terminals. The original intent in creating this dry port was not to relieve congestion along the U.S. East Coast, but to expand the hinterland of the state-owned ports in Virginia and to capture new cargoes. This dry port now serves markets in Pennsylvania, northern Virginia, West Virginia, Maryland, Washington D.C. and eastern Ohio. Although this was a public sector investment on the part of the Virginia Port Authority, it was made on a purely commercial basis, with the dry port taking several years to become economically viable. Factors which have helped the dry port achieve economic viability are: the marketing support provided by local economic development agencies and the state's Economic Development Partnership, lower land costs, lower taxes and a lower cost of living. All of these factors have helped attract distribution centers into the area around the dry port, which has further contributed to its success.

From an economic perspective, there are several factors that need to be considered. The cost perspective of prospective customers is very important in this. For freight forwarders the use of a dry port in preference to a seaport option is only attractive if such a change has the effect of cutting costs or at least is cost-neutral. As in the successful case of the **Virginia Inland Port**, companies can secure reductions in the high costs of doing business along the coast, while retaining easy access to international markets. If this happy circumstance is not the case, but it is still decided to implement the dry port concept in the absence of any commercial motivation, there is then a need for some form of regulatory measures to be imposed. However, the sorts of regulatory measures that might be considered will inevitably face the usual political difficulty that there needs to be a deeply-held commitment to protecting the environment in order to take such unpopular measures. From an environmental perspective, of course, the dry port concept only makes sense in the first place if the amount of generated traffic and the aggregate distance it travels, together with the associated environmental pollution, is lower than in its absence.

One argument in favor of implementing the dry port concept is that it helps to ease the shortage of space at a seaport. This raises an important issue in relation to periods of economic downturn as currently being experienced at the time of writing. In 2007, many European seaports were working either close to, or at, their maximum capacities and operators were frantically searching for expansion opportunities. At the time of writing, the number of containers handled is decreasing in the majority of major seaports. As a consequence, shortages of space are sorting themselves out, at least temporarily. This might suggest that the dry port concept may be more relevant during periods of economic expansion or boom periods than during times of recession or depression. However, as has been shown, this is not the only reason why the dry port concept might be implemented. There are also benefits in terms of accessing the existing hinterland, expanding a port's hinterland, capturing cargo closer to source and/or further up the supply chain. In terms of private sector developments of dry ports in practice, there are perhaps elements of all these reasons underpinning Europe Container Terminals's investments in dry port projects in Venlo, Duisberg and Willebroek. The perceived benefits of these dry port projects even for private sector interests might suggest to public policy makers that, in the current depressed economic climate, the discussion may need to be taken further in the tradition of the monetarist versus Keynesian debate: should the dry port concept be implemented anyway – even during periods of recession or depression – in order to be ready for future expansion of the demand for conventional port capacity? Given the potential negative impact on the rate at which the world economy might recover from its current malaise, it may well be prudent to do so.

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Chapter 19
Importance of Hinterland Transport Networks for Operational Efficiency in Seaport Container Terminals

Joachim R. Daduna

Abstract
In recent decades the intermodal container transport has emerged more and more as the basis for a globalized economy. This results in accordant seaport container terminal requirements as transhipment nodes and as an interface between different modes of transport. However, the performance in the nodes of a network only represents one aspect, as the capacity in the inbound and outbound flows, i.e. the deep sea and the hinterland traffic, has to play an important role in these considerations. To solve the problem of hinterland transport concepts are presented which include a dislocation of the terminal structures as well as a bigger involvement of rail freight transport. Although the rapid growth of the container transport in recent years clearly declined because of the global recession in 2009, no fundamental changes are expected, as shown by current developments (and forecasts). The quantities which have to be dealt with are rising again (and continue to rise), even if with a temporal lag, so that there is still need for action, especially concerning the linking of seaport container terminals with the hinterland.

19.1 Developments in International Container Transport

With the increasing globalization of economic interdependencies, both in industry and in retail trade with a more and more internationally oriented division of labor in production processes, logistics has become a key factor for competitiveness of an economy. An essential basis for this are the technical improvements of transportation and transhipment systems and the resulting decline in transportation time and costs. Due to an increase in service offering in transport markets, the demand

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for transport services raises, i.e, the underlying development induces each other to some extent, leading to a significant acceleration of changes.

An essential point for the further (technical and structural) developments in transport logistics is the increasing containerization with a system depended adaption of mode of transport and corresponding changes in the conceptual design of processes, while the (classical) general cargo loses its importance. The objective of containerization is i.a. to significantly simplify and speeding up the transportation processes between the location of a shipper and the destination of the products in terms of logistical and administrative measures. In the foreground are the processes concerning multimodal transportation chains, within which an additional handling is required based on necessary transhipment operations. The use of (largely standardized) load units results in a significant reduction of handling effort at the interfaces and thus a shortening of process time. This leads to significant improvements of the transportation processes and ultimately to considerable cost savings. Advantages from containerization also occur in the monomodal road transport, while here loading and unloading processes can be made more efficient by the separation of vehicle and load units.

With regard to the globalization of trade flows and the associated inter- and transcontinental connections *S*eaport *C*ontainer *T*erminals (SCT) and (deep) sea container transport play an essential role in a lot of multimodal transportation chains (see, *e.g.* Panayides and Song (2008)). In a large number of relations this mode of transport leads also to a quasi-monopolistic position, because other modes are not suitable, based on capacity restrictions and cost considerations (such as air freight transport), so that they do not present a suitable alternative. Two key indicators of these structural changes are the increasing container throughput (in TEU) at the worldwide most important SCT (see Table 19.1; based on Notteboom (2004) and IAPH (2010)) and the evolution of container ship sizes (see, *e.g.* Gardiner (2009b), p. 36ff.).

Linked to these developments also organizational changes in the (international) network structures are necessarily (see, *e.g.* Fremont (2007)). From the (still) existing (often more area oriented) line hauling there will be a development of (global) trunk and feeder networks (*e.g.* in the form of hierarchical multi-hub networks) which have to be organized accordingly.

The resulting feeder services can be integrated in the increasingly emerging structures of the short sea shipping (see, *e.g.* Sánchez and Wilmsmeier (2005), Baird (2007); Paixão Casaca and Marlow (2009)) and the river-sea shipping (see, *e.g.* Guy and Alix (2007), Charles (2008)), also in view of the efficient management of transport operations. However, not only the seaside linking traffic must be considered, but also the necessary hinterland transport has to be included, through which the cross-linking of industrial and commercial centers in the inland occurs.

Currently these transports within inter- and transcontinental container flows present a potential weakness, which can possibly be a decisive bottleneck in the future. Achieved improvements of internal processes in the SCT through the use of capable systems for the (internal) planning and control and the use of new technologies for handling and storage (see, *e.g.* Steenken et al. 2004 and Stahlbock et al

Table 19.1 Evolution of the container throughput in the 15 (in 2008) most important container seaports (in Mio. TEU)

Harbor	1985	1990	1995	2000	2005	2007	2008	2009(2)
Singapore(Singapore)	1.70	5.09	11.85	17.04	23.20	27.93	29.92	25.87
Shanghai(China)	0.20	0.46	1.53	5.61	18.10	26.15	27.98	25.00
HongKong(China)	2.29	5.10	12.55	18.10	22.43	24.00	24.49	21.04
ShenzhenPorts (China)(1)	0.00	0.03	0.37	3.99	16.20	21.10	21.41	18.25
Busan(Korea)	1.16	2.35	4.50	7.54	11.84	13.27	14.35	11.98
DubaiPorts(UAE)	– (3)	0.92	2.07	3.06	8.62	10.79	11.83	11.12
Ningbo(China)	0.00	0.00	0.16	0.90	5.21	10.65	11.23	10.50
Guangzhou(China)	0.00	0.08	0.51	1.43	4.69	10.26	11.00	11.31
Rotterdam(Netherlands)	2.65	3.67	4.79	6.28	9.30	10.79	10.78	9.74
Qingdao(China)	0.00	0.14	0.60	2.12	6.31	9.46	10.32	10.26
Hamburg(Germany)	1.16	1.97	2.89	4.25	8.10	9.89	9.74	7.10
Kaohsiung(Taiwan)	1.90	3.49	4.90	7.43	9.47	9.20	9.68	8.58
Antwerp(Belgium)	1.24	1.55	2.33	4.08	6.48	8.36	8.66	7.31
Tianjin(China)	0.00	0.29	0.70	1.71	4.80	8.18	8.50	8.70
PortKiang(Malaysia)	– (3)	0.47	1.13	3.21	5.54	7.31	7.97	7.31

[1] Total throughput of Chiwan, Shekou and Yantian Harbor
[2] Preliminary data; [3] no data

(2008)) cannot constitute a sustainable solution to the problems existing in global freight transport. In future, more and more bottlenecks will arise in the hinterland cross-linking of the SCT, even if the forecasted increase of throughput, such as for Hamburg of over 200% on the year 2025 (see Anonymous (2008), p. 70), will not occur on this scale due to the current recession.

Nevertheless there will be a re-increase in the economic growth in the medium and long term view which will lead to significant capacity bottlenecks, especially in hinterland rail transport (see, *e.g.* Eickmann et al (2008), p. 21ff. and Belter and Fricke (2008)). To manage these foreseeable developments in terms of organization and track capacity constraints appropriate solutions are needed with which help the container handling in the (international) network structures could be improved sustainable. More efficiency in hinterland operations resulting from better cooperation and coordination of the involved parties (see, *e.g.* van der Horst and de Langen (2008)) can be one (but not the only) sufficient step to avoid bottlenecks. Therefore special emphasis is needed to take appropriate measures to qualify and to extend the existing (traffic) infrastructure, however, to undertake these implementations it is associated with significant problems in the existing (political) environment and the divergent interests of the different stakeholders.

In the following analysis some basic considerations regarding the improvement of processes in the (international) container transport will first be outlined. Then two possible solutions for a reorganization of the hinterland traffic will be presented with which an increase of container throughput can be achieved.

19.2 Process Design and Basic Conditions

Bases of world-wide organized multimodal container transport are efficient SCT and their sea- and landside cross-linking through the various mode of transport. Seawards it is the connection between the SCT among them by (deep) sea shipping, while onshore the integration of inland terminals using terrestrial mode of transport takes place. To ensure the necessary performance, a cross-network adjustment of the capacities as well as a synchronization of the processes is required. Capacity expansions and accelerations in the processes within the SCT only have little or no effect if the external links are not of sufficient size also. Especially on landside in recent years increasing bottlenecks were evident (as for example in the German Federal Republic) (see, *e.g.* Eickmann et al (2008),p. 21ff; Belter and Fricke (2008)), which, however, do not have such a significant impact anymore, because of the negative global economic developments. This does not mean that this is a permanent change, but rather, it is assumed that in this market segment the demand for transport services will be rising again in future (even if with lower intensity), as the key indicators from the first months of the year 2010 show.

The over the years continuously rising demand and increasing competitive pressure have led to a number of structural changes in the past, focusing on the field of process control in the SCT. The expansion of existing and the construction of new terminals comes along, whereas in view of the investments needed, an increased integration of private sector companies occurs, *e.g.* applying *P*ublic *P*rivate *P*artnership (PPP) concepts (see, *e.g.* Lahl (2007); Keppel (2010)). At the same time an internationalization appears on the part of the terminal operators, which expand their market position in this way as well as an entry of market dominating shipping companies (see, *e.g.* Slack (2007); Gardiner (2009a), p. 30ff.). Some new structural changes appear seawards also, whereas onshore some very significant deficits can be found concerning the efficiency of hinterland transport. The following explanations are giving a brief overview of the structural developments in the past years within the international container transport market.

- *Development of seaport container terminals:*
  The enhancements and efficiency improvements in the SCT (see, *e.g.* Steenken et al (2004), Stahlbock et al (2008)) mainly relate to a shortening of process time (and therewith of lay days in port) as well as to improvements in cost structures. In the foreground is the use of quantitative methods (as well as an increased use of information technologies) in the context of planning and control processes, the use of new technologies in the handling of in-company operational processes and capacity-enhancing measures in the field of terminal infrastructure. Within the basic structures a clear differentiation into three levels arises:

  – *Operational level:* Short-term possible improvements in the organization of in-company operational processes on the basis of existing (handling) technologies and the existing infrastructure.

  - *Tactical level:* Medium term involvement of other (improved) technologies into operational processes in the field of transport, handling and storage.
  - *Strategic level:* Long term oriented measures in the development of terminal infrastructure.

  However, the three levels are not considered to be isolated, because these cannot always be clearly separated, as they influence each other. Out of process planning and operational control can arise that a performance limit is reached with the technologies used, meaning that changes at the tactical level will be necessary. Conversely, measures on this level condition adjustments within the operational level. A similar situation is evident in the dependency between the tactical and strategic level. The problem of time pattern for the realization of possible measures comes along which arise from the legal (and often also politically-influenced) framework and from the available technological possibilities.

  The measures undertaken in recent years have led to some significant efficiency improvements at the operational level, as in the area of sea- and landside process design and yard management. But looking at the key figures for *i.e.* the port of Hong Kong indicates that in many ports the existing potential of efficiency may not yet be exhausted in a desirable range (see, *e.g.* Stenvert and Penfold (2007), p. 27ff.).

- *Developments of seaside linking:*

  With the increased demand for container transport over the years, a need for larger shipping units (particularly in the Asian traffic) is generated (see, *e.g.* Gardiner (2009b),p. 36ff). A necessary condition therefore is a sufficient improvement of the operational performance within the SCT by the use of a suitable technical infrastructure (see, *e.g.* Rudolf III (2007)) as well as the assembly of suitable trunk and feeder networks in order to use system-inherent economies of scale. Most important here are the trunk connections with accordant volume potentials, which form an essential basis for the use of large ocean going vessels (see, *e.g.* Müller and Schönknecht (2005); Gardiner (2009b), p. 36ff).

  A general advantage of these structures is not necessarily given, as transhipment operations within transport chains can be a significant cost disadvantage. Depending on the situation, the use of smaller vehicle units may be economical, as for example within the scope of the short sea shipping (see above), since the number of transhipments is less and even the cost-intensive (terrestrial) hinterland traffic usually can be reduced.

- *Landside linking:*

  As the experience of recent years show, in this area there are the strongest gaps in the organization of (international) networks in multimodal container transport, as the performance of the (terrestrial) mode of transport in the hinterland (road and rail traffic, transport via inland waterways) is limited because of various restrictions (see, *e.g.* Belter and Fricke (2008); Eickmann et al (2008), p. 21ff.). Moreover, the differing performance characteristics have to be considered (see, *e.g.* Daduna (2009)), which indicate the (usually situational) suitability of different modes for container transport.

- *Road freight transport:*
  The low transport volume of trucks and the existing capacity bottlenecks within the (main) road networks are the fundamental traffic related restrictions which exclude the suitability of this mode of transport to cover an increased demand. To add are the discussions about the environmental impacts of the road traffic as well as transport political objectives of changing the modal splits for the benefit of other (low-emission) mode of transport.
- *Rail freight transport:*
  A (relatively) long transportation time, the low flexibility (because of the existing track guiding) and the partial extensive inefficiency in the operational processes as well as the low priority with track allocation for freight transport limit the use of this mode (currently). Another problem is the lack of (transnational) interoperability within monitoring and control technology, energy supply services and track system. The expansion of network capacity can be a solution, but only long term, as the planning and implementation of such infrastructure measures would take a longer period of time. The lack of competition that results from the quasi-monopoly position of former state-run rail carrier also has a negative effect.
- *Transport via inland waterways:*
  The relatively low network density, topographical constraints (width and depth of inland waterways) and weather-related restrictions are of importance. Due to the political frameworks structural and capacitive adaptations of the infrastructure are only enforceable with severe restrictions or not at all, so that this mode of transport can only represent an alternative with the presence of appropriate basic conditions.

Based on the framework outlined above, for long term only the rail freight transport (partially in connection with short sea and river-sea shipping) can provide a sufficient basis for an efficient hinterland transport. From the current (capacitive) availability as well as the expected measures to qualify and extend the infrastructure it cannot be expected that the importance of rail freight transport in modal split will improve significantly.

In view of this situation the following comments are going into two measures that appear capable to meet the long-term (volume based) requirements for the hinterland transport better. The focus here concentrates on solutions for a (spatial) dislocation of SCT structures and for an improved integration of rail freight transport into the hinterland operations. That means the objective is to reach a sustainable change in modal split in favor of rail freight transport.

19.3 Dislocated Terminal Structures

One approach to overcome the spatial restrictions in SCT is the incorporation of dislocated terminal structures. Here nearby satellite terminals are built up, where the basic consideration is to by-pass the limitations of available storage capacities and the targeted bundling of freight flows (see, *e.g.* Slack (1999)). In connection with SCT, they serve primarily the intermediate storage of a part of the import containers for further transport to the hinterland as well as for bundling and an on-demand supply of export containers for shipment. An essential problem is in this context the integration of these conceptual transportation processes as well as the technical systems in the existing structures of an SCT, also regarding the necessary capital and operating costs.

In the foreground stay the questions of possible automation and the required number of additional transhipment operations. With a view to a sufficiently high level of performance and the expected costs shuttle transport based on an automated transport system with its own infrastructure as the cheapest alternative must be considered. This can be a rail transport system with self-propelled units or a road-based solution with the use of *A*utomated *G*uided *V*ehicles (AGV), also as a partial track-guided system. The necessary system requirements exist and have been technologically tested so far, so that only adjustments are required to meet the specific needs. A number of possible solutions in this regard are discussed in the literature (see Dimitrijevic and Spasovic (2006); James and Gurol (2006); Roso (2008); Rosa and Roscelli (2009)), which however have not yet been implemented or at least not in connection with a terminal cross-linking.

- *Use of self-propelled units:*
  In this field there are a number of innovative solutions for self propelled units (see, *e.g.* Siegmann and Heidmeier (2005)), but which are not or very limited used in the rail freight transport. The main causes for this are operational reasons (mixed transport operations with conventional and automated vehicles) as well as legal issues within the admission procedure. An example of such a solution is the CargoMover with an intelligent sensors system for obstacle and track detection, and a control system based on mobile radio (see, *e.g.* Mairhofer (2003); Dellmann and Berger (2006)). In the case of a closed (internal) track network for such shuttle systems the mentioned technical and legal problems are not given.
- *Use of AGVs in road transport:*
  The existing vehicle technology for the road transport enables fully automated driving for both individual vehicles as well as in a platooning. The basis for this are, among other things, electronic equipment developed in the context of driver assistance systems (see, *e.g.* Kücükay and Haney (2004)) in connection with a satellite-based vehicle tracking (see, *e.g.* Mansfeld (2004), p. 107ff; Daduna (2005)). As for the rail transport, legal aspects (see, *e.g.* Happe 2004, p. 122ff.) are the major obstacles for comprehensive and practical implementation for this type of transport operations. Insofar as closed network structures are available,

> such as they are described by Zhang et al (2006) for a dislocated terminal structure, the use of such technique is possible. With regard to the investment costs for the necessary infrastructure the use of track-guided systems represents a possibility in this context, which also enables a simplification of flow control.

In the following the basic structure of the interaction between a SCT and a satellite terminal is outlined. Case-specific (*e.g.* regional) restrictions would potentially lead to modifications in detail, but without questioning the underlying concept. Figure 19.1 shows the integration of a shuttle system in an existing SCT and the connection with the respective satellite terminal, while Figure 19.2 contains the basic layout of a satellite terminal.

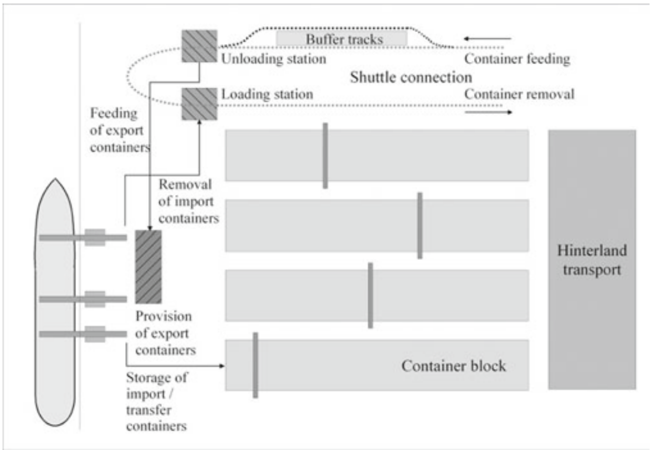

Fig. 19.1 Basic structure of the integration of a shuttle system in an existing SCT to build a connection to a satellite terminal

The operational processes resulting from the shuttle connection to a satellite terminal can be integrated into existing structures, independent of the applied technical approach and of the (necessary) transportation and transhipment operations.

As the availability of sufficient traffic areas for additional, it makes sense to create at least parts of the infrastructure for the shuttle system in a elevated construction. Beneath the more efficient use of space, the separation of the traffic on two levels provides the possibility of an increased automation of transport processes in a satellite terminal (and even with appropriate adaptations in an SCT). This concerns in particular the land-side vehicle use at the interface to the hinterland transport. Here, it often comes to a spatial overlapping of the often dominant hinterland road freight transport (for in- and outbound container flows by manually driven trucks) with the shuttle operations to serve the rail head. Because of the legal framework, a simultaneous use of automatic and manually controlled transportation is not permitted, which leads to limitations in the technical system design. With the spatial separation this restriction can be overcome, and this gives relevant design options.

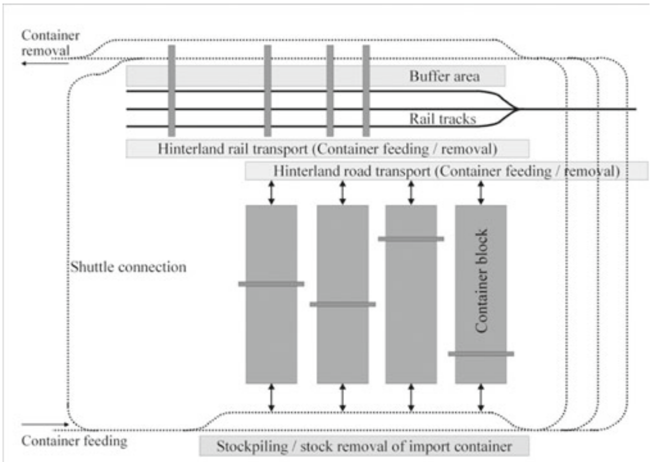

Fig. 19.2 Basic layout of a satellite terminal

As shown in Figure 19.2, a satellite terminal includes not only additional yard capacities, but also presents a gateway expansion for hinterland transport. The focus here is the link to road and rail transport. If appropriate geographic conditions are given, such as an available and sufficiently capable connection to inland waterway networks, this mode of transport can be included as well. A specific variant are satellite terminals, which are designed for transhipments to predefined modes of transport. Examples are dedicated terminals, exclusively for inland waterway transport (including, where appropriate, the river-sea shipping) or feeder transport. These allow a systematic segregation of types of vessels, so that the quay allocation and transhipment operations in the respective terminals can be controlled more efficient (and cheaper as well), *e.g.* by the use of vehicle-specific transhipment techniques.

Associated with the introduction of satellite terminals are investments for the construction of facilities and the providing of necessary transportation systems as well as additional operating costs and possibly losses in logistic flexibility within the terminal operation. Important factors here are the distance between the SCT and the satellite terminal as well as the transport volumes to be handled. A general statement about the advantages of such a decentralized solution is not possible, as, regarding the costs, the local conditions and existing structures of the SCT are considered as important matter.

19.4 Options to Use Rail Freight Transport

Another way to improve the performance of SCT is an increased use of rail freight operations in hinterland transport. The initial point here can be two approaches, the use of direct connections to capable inland terminals (dry ports) in the hinterland (see, *e.g.* Jaržemskis and Vasisliaukas (2007); Roso (2008); Roso et al (2009)) as well as the integration of Megahubs in the organization of container flows. The aim is to bypass the storage of some of the containers in the SCT and thereby shift some of the sorting and allocation processes into the hinterland.

- *Direct services to inland container terminals:*
  The basic idea of this concept is the direct evacuation of unloaded import containers considering a presorting for different destinations. (Block) trains are provided for hauling unloaded containers into the hinterland without (local) intermediate storage. Then the delivery out of the inland container terminal takes place via road transport to the usually in the surrounding area located customers. Such a solution, however, is only of limited use for an on time supply of export containers to be shipped in a SCT. Difficult are a sufficient level of demand for a scheduled block train and the availability of sufficient yard capacities in the inland terminals, to enable a possibly multi-day intermediate buffering of containers. With the time-related requirements for the container supply and the possibility of occurring disturbances in the transport processes in mind, a sufficient time buffer must be considered in advance, so that in that case a (short-term) storage in the SCT must be possible.

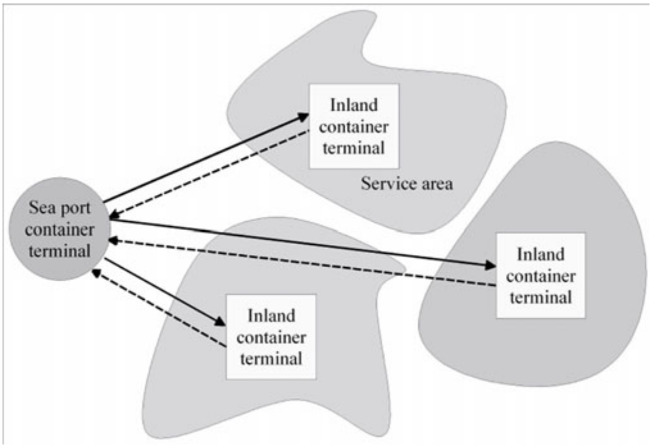

Fig. 19.3 SCT connection to inland container terminals

If a SCT has a sufficiently capable connection to an inland waterway network, an accordant concept can be realized for this mode of transport (using push barges). The lower speed has to be considered though, which could be compensated in case of direct evacuation after unloading the containers, because of the abolition of possibly multi-day waiting time in the SCT, at least partial. With the use of pushing units, additional abilities show up, as a single push barge can be distributed locally along an inland waterway-route and therefore the transport process of loading and unloading can be separated, whereby significant time advantages can be achieved. The supply can be organized analog (centralized and decentralized), although a sufficient time buffer in advance is necessary, because of the speed problem. A too early arrival at the SCT is uncomplicated, as the push barges can be used as temporary interim in such a situation.

- *Incorporating of Megahubs:*
  A major simplification of procedures during evacuation of the unloaded import containers can be achieved, if the Megahubs are setup within the containerized rail freight transport (see, *e.g.* Bostel and Dejax (1998); Alicke (2002)). In this case a prompt evacuation is possible, largely without consideration of destinations. The result-oriented allocation here is (usually) not conducted in the SCT, but moved into the inland hub. This simplifies (and speeds up) the processes considerably, as important time advantages can be achieved within suchlike structures in a hub with a direct exchange ("transfer") of load units between several trains (see Figure 19.3). If no direct transfer of some containers is possible within the hub, they can be stored temporarily (up to a certain extend). At the same time Megahubs form an interface to road transport, particularly in consideration of the distribution (or collection) of containers in that (surrounding) area.

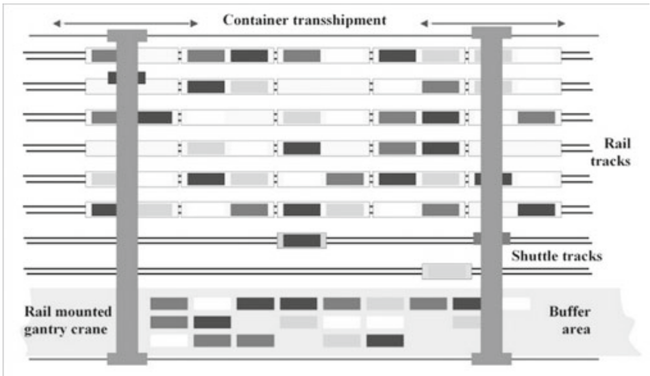

Fig. 19.4 Megahub system concept (basic layout)

In the opposite direction, which means the supply of export containers to a SCT via Megahubs, an aggregation occurs analog to the procedure outlined above, whereas these processes (shown above) are clearly more difficult to organize. A basic aspect here is the question, whether a temporally buffering is possible within the different hubs, so as to ensure an exact (real-time) control of the supply for the shipment.

The factual service capacities and potentials for efficiency of Megahubs are based on the introduction of integrated hub-structures within large-scale (international) rail traffic (see Figure 19.4). Because of the existing bundling effects (and the associated increase in capacity utilization) as well as the increase of the occurring transhipment operations the competitive position of rail freight transport is improving considerably, as it is possible to decrease the operating time of the containers significantly without using point-to-point transport, *i.e.* instead of an (meshed) network, based on direct connections, a multi-hub network structure is set up. At the same time, the partially unavailable interoperability based on technical differences between the applied systems can be resolved, as they exist for example within the European rail network. Simple transfers between networks with different track gauges, for example, can be simplified and made cheaper, if Megahubs are used as interface.

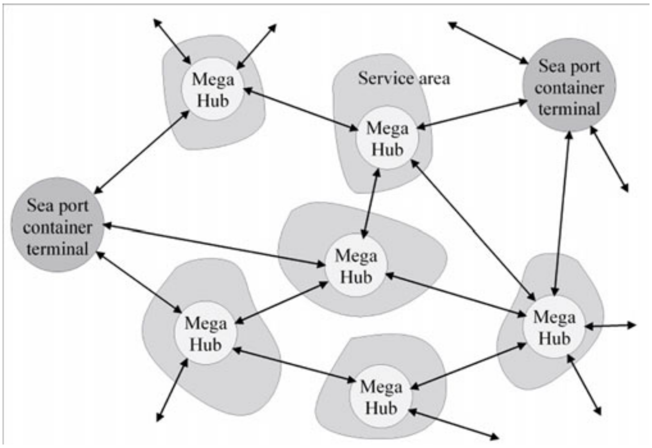

Fig. 19.5 Structural linking of SCT and Megahubs

Analyzes of Limbourg (2007)(p. 141ff.) show, that based on adequate structures a net of Megahubs (within Europe) will give the possibility to reorganize rail freight transport. This service improvement within (transcontinental) rail traffic must be seen as necessary condition to change the modal split in the seaport hinterland transport shifting container flows from road to rail. The for such a concept sufficient transport volume , which is a necessary condition for an economically successful establishment of such network structures, exist and will also be available long-term. This follows from the above mentioned forecasts about the development of throughput in the north range SCT (see, *e.g.* Anonymous (2008), p. 70), which are believed to have a (long-term) corresponding potential of demand for rail transport, even if a clear decrease occurred firstly, because of the economic crisis in 2009.

In addition, the introduction of (largely meshed) network structures (see Figure 19.5) and the integration of SCT in those structures is an essential basis to improve the efficiency in container transports sustainable, especially in the transport processes. An interesting area here could be, amongst other things, the integration of land bridging transports between two SCT, which may be considered as operationally reasonable (and therefore economically justifiable) within appropriate conditions. This allows improvements in container transport and also reduces the capacity constraints of heavily used SCT.

A requirement for a comprehensive shift of container flows to rail transport is a fundamental reorientation of transport policy, not only in Germany and the *E*uropean *U*nion (EU). The currently available network capacities are in no way sufficient to cope with the quantities that must be handled in the future by rail transport. Even if additional potentials can be made available by an improved track management, this is not solving the basic problems.

Because of the foreseeable capacity problems exists a requirement for a widespread and on macroeconomic structures oriented network expansion, particularly in the relations between to be built Megahubs or rather to be used inland container terminals. Important to discuss here is also a change of the product hierarchy in rail traffic, in which the freight transport has been of relatively small importance compared to the offerings of (long-distance) passenger transport. A key point here can also be a network design that allows an (extensive) segregation of traffic, *i.e.* by what the competition problems between the different products are reduced. Therefore, the main focus has to be an on macroeconomic structures oriented network expansion, since only this could be the long-term basis for sustainable change of modal split in favor of rail transport in the hinterland of the SCT.

19.5 Conclusion and Outlook

The strong increase of container transport in recent years is recognized in the worldwide and undeniable, independent from a discussion about the (current) demand decreases and the expected long-term growing market. This leads to constantly increasing requirements on logistics in these transport networks, both in the nodes (the SCT and the hinterland terminals) and in the sea- and land-based cross-linking. Since the existing capacities will not be sufficient for the expected demand, the question of responsibility has to be asked and answered. The problem here is that these are distributed differently, since both private sector interests and public responsibilities are included, *i.e.*, which measures are to be taken by whom.

For the mostly inter- and transcontinental links of the SCT, the fundamental responsibility (largely) lies in the competency of the shipping company owners. As a persistent increase in vessel capacity, both in number and in capacity (see, *e.g.* Notteboom (2004), Heymann (2006), p. 6f. and Stenvert and Penfold (2007), p. 16ff.) is recognizable, currently no bottlenecks are expected in this area, as in this case it can be reacted relatively short-term. The responsibility regarding the capacitive expansion and increase in efficiency within the interfaces lies (essentially) with the owners or operators of the terminal, although political institutions often are (partial) included due to ownership structure. Even in this (technically operational) field it can be reacted relatively short-term, as the responsible operators or owners can act largely independently in accordance with the spatial restrictions and market requirements. If it is about changes or expansions of infrastructure that are subject to public-law approval procedure, the political institutions have to be included. These than are also responsible for the provision of macro logistical structures, *i.e.*, the necessary transportation networks, which have to be observed (as mentioned above) as the most important bottleneck factor and therefore also forms a key competitive factor for the ports.

So not only today the industry and trade associations are clearly raising the request to ensure the provision of (especially long-term) needed infrastructure, especially for an efficient rail freight transport. It must be considered that the mobility of goods (and people), even if other claims arise again and again, is an absolutely necessary condition for a sufficient economic growth (see, *e.g.* Ickert et al (2007), p. 111). From this follows an urgent need for action at the level of policy makers, also in view of the (above mentioned) periods for the necessary planning and decision processes as well as for the realizations that have to be considered in infrastructure measures in this field. A critical point here also is (especially in most EU countries) the current setting of priorities in the use of available funds for rail transport, which is characterized by a strong fixation on the long-distance passenger transport. It has to be asked whether it may be useful in macroeconomic terms, to build up highly subsidized services (with public funds) in competition with passenger air transport and to neglect the pressing needs of freight transport to a large extent. Sufficient network capacities for rail freight transport can also be an incentive for the emergence of new rail freight carriers, as long as they exist, which may result in an expansion of supply and in an intensification of competition and hence (at least in medium- and long-term) in a significant performance improvement in this mode of transport.

In view of the apparent market development and the resulting traffic requirements an urgent need for action exists. Besides a (partial) substitution by short sea and river-sea shipping only the rail transport (see, *e.g.* Eickmann et al (2008), p. 21ff., Breimeier (2009) and Schönemann (2010)) and to a certain extent the transport via inland waterways (see, *e.g.* Notteboom (2007)) can be understood as a long-term sustainable solution for terrestrial container transport. In addition to the configuration of dislocated terminal structures to expand the capacities of the SCT, measures to improve efficiency of hinterland transport have to be initiated. The foreground is initially the national level, although the integration into the *T*rans-*E*uropean *N*etwork (TEN) structures should be considered, as these are seen as a crucial backbone of cross-border rail transport within Europe. Failure to provide the necessary infrastructure and to create the organizational conditions of SCT may arise in significant disadvantages in port competition (see, *e.g.* Wiegmans et al (2008) and Notteboom (2009)) and also in negative impacts on macroeconomic development in the future.

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Chapter 20
Specialized Planning Issues

A Policy Perspective on Sea-Rail and Sea-River Connections

Orestis Schinas and Christos Dionelis

Abstract
Currently most cargoes leave the terminal by road; in Europe, at least, this trend is not sustainable, and sea-rail and sea-river alternatives shall undertake more loads. The focus of this document lays in Europe, including policy and market trends in the European Union, however the problems and the potential solutions may have a global interest. In the text a thorough examination of policy developments in the fields of rail, inland waterways and intermodality is presented. Environmental issues are also discussed. The data from EUROSTAT is used as a basis for further analysis, where it is revealed that even if there is strong political support, it is questionable as to whether it is feasible to promote these links as soon as 2015 or even 2020. The concept of dry (inland) ports and their function in the canalization of cargoes is also analyzed in view of sea-rail and sea-river links. In the last section, all points are summarized and some recommendations are presented.

20.1 Introduction

A seaport is essentially a nodal point in logistics networks, acting as a link in a chain where cargo flows change mode or vehicle of transport. Seaports can only fulfil this nodal role if all modes of transport function optimally; they have a strong interest in efficient and sustainable maritime, road, rail and *I*nland *W*aterway *T*ransport

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(IWT). More and more competition between ports is apparent in the hinterland and the provision of inland access.[1] Furthermore, arrangements such as of a *F*ree *T*rade *Z*one (FTZ) and generally port clusters, where a 'port cluster' consists of all economic activities related to the arrival of ships and cargoes and located in the port region increase the economic significance of a port at national or regional level (see De Langen and Chouly (2004)), also attracting the special attention of transport planners, business decision-makers and finally of policy-makers.

Due to the central role of seaports in international supply chains, the issue of "port hinterland" is a task with prominent importance for ports themselves or their respective region, representing a big challenge for all involved players, as the complexity of arising problems is frequently huge.

Literally, hinterland refers to the land (but to what extend?) behind a city, a port complex, or a sea-land interface nodal point. Moreover, hinterland means the geographic area, where customers of the port are located, or more precisely the set of origin and destination locations that are logistically served through the specific port under normal circumstances. Fageda (2000) suggests the following definitions for the *hinterland*. It is

- the area where a port enjoys a monopolistic position, and
- the origin and destination area of a port, that is, the inner region provided by a port (see Fageda (2000)).

In summary, hinterland consists of the natural market reach of the port, *i.e.* the areas from which cargo originates, as well as the areas where cargo moving through the port is destined. Some ports enjoy hinterlands that extend across many states and regions. Traffic in European seaports is growing at a fast pace, on average 4% per year, for container traffic between 7% and 15% per year and a significant growth of inter-EU seaborne trade (see COM (2009a), p. 137–140).[2] Some more detailed statistics suggest:

The table above clearly suggests that ports have globally experienced an annual increase of 8.3%, in terms of TEU, a measure used for capacity in container transportation. throughput, while in the last five years the growth rate has been reduced to 5.5% and in the last two reported years (2007 and 2008) to 3%. However, statistics yield a decrease for European and American ports, whereas growth is substantial in Asia. A closer look at the statistics and the economic activity, suggests that this trend will keep up, as the *G*ross *D*omestic *P*roduct GDP and Industrial Production forecasts indicate a slow recovery of the EU, a rather more encouraging one for Japan and the USA and an impressive one for China, Japan and the newly industrialized countries of Asia:

From the same sources, one receives the information that the average industrial production has sharply fallen in 2008; in Eastern Europe (-10.97%), in Brazil (-

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[1] Although this is a generally accepted point, an interesting paper of De Broge et al (2007) focusing on its modeling is recommended for further reading.

[2] Most of the figures of this paper are based on *EUROSTAT* statistics. *EUROSTAT* is the Statistical Office of the European Communities situated in Luxembourg. Its task is to provide the European Union with statistics at European level that enable comparisons between countries and regions.

Table 20.1 World Port TEU Throughput (see Clarkson (2010))

Date	Europe	Americas	Asia	World
1994	12,226,921 22%	10,318,420 19%	32,347,032 59%	54,892,373
1995	15,112,209 18%	17,136,590 20%	51,631,682 62%	83,880,481
1996	17,931,866 20%	16,923,802 19%	55,410,159 61%	90,265,827
1997	21,949,049 21%	19,367,808 19%	60,828,853 60%	102,145,710
1998	25,129,866 23%	20,949,427 19%	64,631,844 58%	110,711,137
1999	27,036,702 22%	22,618,117 19%	72,027,590 59%	121,682,409
2000	29,742,366 22%	25,082,626 18%	81,358,117 60%	136,183,109
2001	30,547,512 22%	24,697,451 18%	82,063,896 60%	137,308,859
2002	33,132,383 22%	26,600,404 18%	91,537,831 61%	151,270,618
2003	36,003,755 21%	29,266,140 17%	102,290,806 61%	167,560,701
2004	40,810,053 22%	32,292,898 17%	115,431,542 61%	188,534,493
2005	42,754,333 21%	34,798,113 17%	124,667,614 62%	202,220,060
2006	45,457,001 21%	37,466,865 17%	136,839,700 62%	219,763,566
2007	52,107,923 22%	35,601,580 15%	151,709,311 63%	239,418,814
2008	51,662,655 21%	35,535,886 14%	159,506,859 65%	246,705,400
10 Y	7.5%	5.4%	9.5%	8.3%
5 Y	4.8%	1.9%	6.7%	5.5%
07-08	-0.9%	-0.2%	5.1%	3.0%

14.5%), in Japan (-20.6%), in the USA (-7.8%) and in the OECD (*O*rganization for *E*conomic *C*o-operation and *D*evelopment) countries (-11.65%) the economic recession was evident, in contrast to China (5.7%).

Table 20.2 GDP reported and forecasted (see Clarkson (2010) as per data of the International Monetary Fund)

Date	Germany	UK	EU	USA	Japan	China	India	Newly Industrial Asian States	World
2008	1.29	0.71	1.84	1.11	-0.64	9.05	7.29	1.55	3.20
2009	-5.61	-4.09	1.67	-2.75	-6.20	6.52	4.52	-5.62	-1.32
2010	-1.00	-0.40	2.60	-0.05	0.52	7.51	5.61	0.82	1.89
2011	1.48	2.12	2.75	3.35	2.17	10.25	6.89	4.37	4.29
2012	1.83	2.94	2.76	3.64	3.17	10.67	7.59	4.82	4.84

These figures clearly indicate that new investments are necessary in port infrastructure as well as maritime access and hinterland infrastructure to avoid congestion. At this point it should be noted that the center of attention of the current document lies primarily in European issues, since the availability of data and of policy documents was the decisive factor for this focus, yet the approaches may have an application in other regions as well. Congestion off the port zone is evident in many other regions, such as in the USA, China and South-East Asia.

It is also generally accepted that measures aiming at improving ports' connections to the hinterland are imperative. Today, road connections play a major role in the continuation of transport to and from ports. However, the continuous increases of container traffic and the deterioration of road system capacity ask for better connections and increased capacities at the ports(see COM (2006b)). Road connections are no longer enough anymore at least in the northern regions of the EU. They cause many problems accessing to the ports' vicinity through cities and their capacity cannot cope with the increasing tonnage coming to the ports. In this respect, better access of railways and inland waterways into the ports' infrastructure and operations should be promoted. This has been well understood by the policy makers. The European Commission's intention to propose an action plan to encourage the emergence of a rail freight-oriented network, allowing for dedicated freight corridors, could therefore be a very good step towards multimodality (see COM (2007b)). The term multimodality is used according to the common European Commission's definition, given in the beginning of Section 20.3 below. Intermodality is a quality indicator of the level of integration between the different modes: more intermodality means more integration and complementarity between modes, which provides scope for a more efficient use of the transport system.

Seaports are natural partners for rail. They are not only nodal points for rail, *i.e.* where the cargo is put on and off the trains; they are also often an active player in the provision or management of rail transport. In most European ports, the port authority or managing body of the port has formal responsibilities with regard to rail operation and/or rail infrastructure inside the port area. This is the case of the Port of Hamburg[3], of Antwerp,[4] and of many other ports. Seaports are also more and more participating in railway projects within and (even far) outside the port area, as congestion in their hinterland may hamper their operation (see, *e.g.* HHLA (2010)). Notably some seaports belong to or are administratively bounded to the rail authorities and enterprises, as is the case in Turkey, thus highlighting the sine qua non operational links of seaports and rail connections to the hinterland. Furthermore, inland waterways can perfectly cooperate with maritime transport. The cases of major ports like Rotterdam and Antwerp prove that in a suitable environment, the two modes can really operate quite successfully (see PoR (2009)).

The current work examines the issue of sea-rail and sea-river operations and investigates its background, its problems and its potential, mainly from a European policy-making point of view, as most of the problems envisaged in this kind of operation are not of a technical but of an institutional and regulatory nature. Section 20.2 explains the content of maritime logistics and intermodality, focusing on the existing strong trends for containerization and on the subsequent problems it creates. Section 20.3 elaborates in detail the issue of logistic chains. In particular, the Section focuses on the key-nodes of these chains, *i.e.* the Seaports. Section 20.4 focuses on the links of the logistic chains, and therefore, tackles the issue of transport corridors, focusing particularly on the railway corridors and the inland waterways. In this respect, the Section analyzes the issue of the policies for the co-operation of maritime transport, railways and inland waterways and refers to the serious, and

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[3] For more details, visit the site of the handling company Hamburger Hafen und Logistik AG (see HHLA (2010)).

[4] Updated and detailed information on rail access and services at PoA (2010).

current problems. Section 20.5 provides certain conclusions and recommendations for the above items.

20.2 Maritime Logistics and Intermodality

An overview of the freight industry trends over the past 15 years show that:

- Maritime transport is the dominant means for international trade. The importance of seaports for European welfare, trade and economy as well as their key position in the European transport network can hardly be overestimated. Almost all of the Community's external trade and almost half of its internal trade enters or leaves through the more than 1,000 seaports that exist in the 20 maritime Member States of the *E*uropean *U*nion (EU) (see COM (2009a), p. 104 and p. 139). Without seaports, the EU would not exist as an economic world power. Without seaports, there would be no internal market.
- Over the last years, larger vessels are being introduced into the container networks. Table 20.3 provides a general view of the situation regarding the introduction of various vessels' generations into the container networks.

Table 20.3 Introduction of vessels and TEU capacity into the container networks (see Dekker (2005), p. 91)

Generation	Year of Introduction	Maximum Transport Capacity (TEU)	Maximum Lenght (m)	Maximum Beam (m)	Maximum Draught
1*th*	1964	1100	200	27.0	9.0
2*nd*	1967	1800	240	30.0	11.5
3*rd*	1974	3000	300	32.0	12.5
4*th*	1984	4500	310	32.3	12.5
5*th*	1995	6000	350	38.0	12.5
6*th*	2003	8000	323	43.0	14.0
Suezmax[5]	2006	12000	400	52,5-56.0	14,6-15,5
Post – Suezmax	Under Consideration	18.000	470	60.0	15,7
Malacca – Max	Under Consideration	>18.000			21.0

The increase of the size of the container vessels follows strictly competitive needs, and the accuracy of the forecast of the ship size is critical for liner operators, as they have to decide the optimum size for a life cycle analysis and not only for existing market conditions. Port operators must also design and invest

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[5] Data based on particulars of MS Emma Maersk, a container ship owned by the A. P. Moller-Maersk Group (see EM-Info (2010)).

in new facilities considering the ship size development. As an example, modern hub ports require terminals with depths of 16m–18m, berths of 400m in length, cranes of 63m outreach for servicing the new mother ships, yet currently only a few ports such as Rotterdam, Singapore, Algeciras, and Salalah (Oman) have terminals with 16m deep. These port facilities for large ships demand high investments and cost, but such expenses cannot be properly reflected in the private shipping cost. In conclusion, the increase of ship size is resulting in a concentration of demand at major gateway ports for the EU – specifically on trades to and from East Asia, focusing demand at certain key ports. The impact of this on the overall structure of EU trade should be evaluated, as these few seaport hubs may become checking points for the logistic activity due to the increased volume of TEUs they handle, or infrastructure hurdles and operational predicaments (even remotely located from the seaport hub) may hamper the smooth flow of goods. Sea ports such as Rotterdam, Antwerp and Hamburg, currently able or planned to serve these mega-ships increase their relative logistics importance and their yard operations as well as their hinterland connections should be as agile as possible, otherwise these vital flows will be obstructed. As shipping lines deploy larger ships on the main trade routes, often in consortia or alliances with other lines, it is either practically impossible or economically unattractive for them to call many ports. Hence the continuous increase in transhipment between hub and spoke ports is explained, as well as the minimization of dwell time at the seaport becomes a critical success factor for both ship and port operators. It has been estimated that 26% of world port movements are transhipment (Heymann (2006)).

- There is a significant growth in containerisation within the general cargo sector. Intense containerization of specific products is also a factor, for example cars, timber products and refrigerated goods. World container traffic, as measured by the number of TEUs handled at ports, has been growing at 8%–9% pa over the last decade. This growth rate is smaller than the growth in the number of units, because of the gradual increase in the proportion of 40 ft containers. Also 40 ft boxes tend to handle bulkier, but not necessarily heavier items. The growth rate in units is also greater than the tonnage or real value of cargo recorded in trade data, because of the increase in multiple handling of containers by different ports across the world.
- The routes used by EU trade change, mainly due to the increasing significance of the Mediterranean and (in the future) Black Sea gateways for central and Eastern Europe.[6] In this sense, the port capacities and inland distribution routes capabilities should be re-assessed taking into consideration the new situation; Mediterranean ports increase their significance, and therefore, capacity issues will be raised. Their hinterland connections will also be strained and their efficiency will at large extend determine the successful distribution of flows

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[6] Worldnet Project: Freight flow between Europe and the rest of the world (FP6 Project).

through the southern and northern ports, instead through the currently northern ports.

- In the liquid bulk trade the trade directions into the EU should be reassessed, taking into account the latest developments of this specific market, and the new plans for pipelines coming to Europe from the East. The new pipeline-projects, the new energy hubs along the EU, currently under construction or recently put into service, will affect the routes and the calls of ships as well as of the total transportation demand (in ton-miles).

20.3 Logistic Chains – Intermodality

According to a definition provided by the European Commission, "Intermodality is a characteristic of a transport system that allows at least two different modes to be used in an integrated manner in a door-to-door transport chain (see COM (1997))." In this context, the goal is to integrate more than one modes of transport in a continuous transport chain. The current problem is that this goal has an impact on the European politicians, on the societies, on the environmentalists, however still not on the markets. There are two main reasons for that:

1. It is rather difficult to organize and establish these continuous[7] transport chains.
2. The expected benefits are appealing; shifting cargo to intermodal transport results in some clear social benefits in terms of externalities, such as a reduced number of expected fatalities and environmental burden, as well as it may enhance the sustainability of the system by avoiding some long term threats, such as the future lack of infrastructure capacity, yet these benefits cannot justify private investment and modal selection, therefore a political support or intervention is considered to be necessary. Simply highlighting the benefits for the environment does not help, and therefore very few intermodal players have developed a constructive marketing approach. The motive for shifting to more friendly combinations has also been quantified at 2 per 500 ton-km by the European Commission, also implying a relationship between externalities and benefits (see COM (2009b)). The estimation of the external cost per mode, as well as the methodology and the economic principles behind it, raises concerns and debates. However, the above price is used for subvention purposes, when shifting cargoes from pure road to either rail or inland waterways or shortsea shipping transport alternatives.

Costs and revenues do not favor intermodal transport from a business perspective. This is because there are always impediments and friction costs arising when there is a change of mode during a journey.[8] This usually results in higher prices, longer

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[7] "seamless" is another popular expression

[8] The major costs related to transhipment are additional loading and unloading, storage, transaction costs, port wharfage, other charges, etc.

journeys and more delays and, consequently, has negative impacts on the competitiveness of intermodal transport.

However, there are certain indications that things may change in the future. First, there is the strong will of the policy makers to promote intermodality. Of course, politicians cannot directly influence the markets, but nevertheless, the fact that they settle the rules must never be underestimated. Second, it seems that with the continuing globalization of trade, transport market structures are changing. Intermodality is becoming more important, at least the combination of sea with rail or inland waterways. This not only applies to container traffic but also to the conventional bulk freight.

The previous statement about the increasing importance of combination of sea with rail or inland waterways has a strong political background, at least for Europe. The European Commission has many times expressed its will to support rail and inland waterways freight operations fed by maritime traffic at major ports.

The mid-term review of the 2001 Transport White Paper (see COM (2001)) addresses, among others things, the issue of connecting the different transport modes, indicating that increased investment within ports and towards the hinterland is necessary in order to improve and extend services so that ports become poles for growth instead of potential transhipment bottlenecks (see COM (2006b)). This mid-term review supports the implementation of the priority projects within the *T*rans-*E*uropean *N*etwork for *T*ransport (TEN-T), most of which are railway projects. Hinterland connections by railway to and from ports are receiving and will receive even more special attention for improving connections between the maritime façade and the hinterland. In this context, the promotion of a rail freight oriented network as well as an inland waterways network and the proposed logistics action plan will play an important role, strictly connected to the ports policy.

Deliveries between industries are a booming business, as semi-finished products are transported to and from industrial firms on their way to locations all over the world. Consequently, the integration of the transport process into the overall logistics system and industrial production processes is becoming increasingly important. Individual transport undertakings, whether they were shipping companies, inland ports, transhipment firms or haulage contractors, were unable to cope with the systemized integration of intermodal transport into overall logistic, industrial processes. It could be an advantageous for the market if the continent-related part of international supply chains could be organized by multitude modes of transport (*i.e.* intermodal) and not by only a single mode (*i.e.* usually by trucks). The creation of big logistics companies used to operate internationally could promote this evolution. Yet, these logistics firms should be convinced that the more complicated intermodal transport chain could become more advantageous than the more organizationally straightforward, door-to-door transport by road. To that end and referring to Europe, the specific advantages of European/ content-related intermodal transport chains especially based on European railways and inland waterways (cost, reliability, environmental benefits, ‘green’ marketing, and possibility of saving on storage) must be clearly indicated.

In a few words, the cost of transport of intermodal transport is still higher than the cost of transport by road, and this is the major problem of combined transport. However, there are the external costs and benefits that, at least for Europe, promote the concept of intermodal transport. The most important advantages of combined transport are reduction of road traffic (less congestion on road network), road safety and ecological aspect (air pollution, *e.g.* CO_2 emissions), noise, environment, and development of urban space and energy consumption. However, one should highlight that the aforementioned explanations focus on the cost, as price faced by the market actors; external costs are not internalized. If external costs were internalized then unimodal options, such as road haulage, would be estimated at considerably higher levels, due to the environment burden, in terms of unit energy required and unit burden.

To that extent, improving the logistical quality and efficiency of intermodal transport is a key objective. The efficiency of intermodal transport depends on the efficiency of the transport means that are involved in the transport chain, on the efficiency of transport corridors and on the efficiency of operations at terminals; all of these components must be planned and function in an integrated manner. Logistic quality refers to improving logistic solutions and smoothening the processes of intermodal transport, as per *K*ey *P*erformance *I*ndicators (KPI), quantifiable measurements for benchmarking and monitoring of achievements based on corporate goals.

The promotion of what is referred to as intermodal transport logistics is a key element of European transport policy. It involves the creation of technical, legal and economic framework conditions as well as innovative concepts relating to logistics for the optimum integration of the different modes of transport for a “door-to-door” service. It particularly concerns the integration of environmentally friendly modes of transport, such as rail, inland waterways and short-haul maritime links, into the transport chain.

20.3.1 The Key-Nodes: Seaports

Maritime terminals are the most critical nodes in the transportation network: containers arrive and leave by ship, truck and train, and the container terminal operator has to optimize all the operations involved in the flow of containers in order to achieve the maximal overall productivity, which is expressed in terms of some opportune performance indices. Such facilities can basically perform two kinds of operations: transhipment and gateway. The former consists in shifting containers from one vessel to another, whereas the latter deals with the import/export of seagoing containers through hinterland transportation. In both type of operating cycles, the yard is used as a buffer for container storage, until loading on vessels, trucks, trains or barges is performed.

Transhipment takes on various forms. The traditional and most easily identifiable occur where export cargo is taken by feeder vessel or cargo ferry from one country to another, usually on the same continent, for onward shipment onto another vessel to a third port, usually in another continent. Import cargo follows the reverse process. This type of transhipment can be controlled by either the shipping line or by the shipper (commonly freight forwarders with excess market power).

Line transhipment arises from coordinated schedules of mainline and feeder vessels controlled by the line. Shipper transshipment is more stray or unsystematic, exploiting the services of different lines or modes in order to reduce transit times or costs. The individual shipping line, consortia or alliance concerned, fully controls a different form of transhipment (relay). This involves cargo carried on one main line vessel relayed to another main line vessel at a hub port. An example would be cargo traveling from East Africa to North America, being carried on a mainline vessel on the trade leg from East Africa to Europe, and then transhipped to another mainline vessel on the transatlantic trade leg.

Co-ordination of sailing schedules and concentration of calls at one port are needed to make this operation efficient and attractive to shippers. While all transhipment is more sensitive to port costs and efficiency of handling rather than direct cargo, relay traffic is particularly sensitive, as the range of ports, which can act as a hub, can extend over a wide area.

Alternatively, transhipment can be distinguished as either natural or discretionary. Natural transhipment is defined by the relay of boxes, incidental to a shipping lines' main origin and destination cargo, with feeder vessels supplying specific markets. In contrast, discretionary transhipment occurs where boxes are moved on main-line vessels as part of a major operation organized by the line, but could be handled at a selection of ports (see DfT (2010), p. 7–8).

Gateway operations are largely more complex as they include inland transportation, so they have to face the potential bottlenecks and inefficiencies in such a phase. Therefore, one of the key points is to ensure enough capacity of penetration into the hinterland, keeping the pace of maritime traffic flows.

As previously discussed, the current trends in liner shipping show a growing trend towards economies of scale in vessels, which means larger full-containerships and dramatic "call sizes" in ports. Therefore, terminal operator must be able to handle maritime containers as quickly as possible, not only with reference to berth performances, but also to hinterland transportation, in order to effectively defend the current customer's portfolio. From a theoretical viewpoint, the two inland means of transport are trains and barges, that are capable of better supporting the call size of deep-sea vessels, connecting the port with the hinterland and shipping large volumes of containers. Despite its existing inherent problems, intermodal transport, if well-managed, can provide competitive tariffs and services, as well as impose low external costs to local communities. For the above reasons, leading container terminal operators in the world, willing to handle high volumes of gateway traffic, set up efficient and high density connections with the hinterland. In this respect, some successful experiences must be cited: the US west-coast ports such as Los Angeles, Long Beach, Seattle and Tacoma for the land-bridge via rail, and Rotterdam and Antwerp for inland barging connecting the North Sea with Central Europe.

Besides such an example of excellence in managing inland flows, hinterland transportation often becomes a potential weak point for a port, as there is a risk that it will make fruitless the efforts of the terminal operator in quayside and yard operation. In fact, a dramatically low rail-traffic share in seaports is often determined by heavy infrastructural constraints (available time slots, ruling gradient and so on) coupled with scarce financial capacity for the realization of new railway lines (Parola and Sciomachen (2009)).

Constraints and insufficiencies may also occur via inadequate strategy of the terminal operator; the port authority's limited vision in supporting a balanced and environmentally sustainable modal split; an insufficient coordination between the leading actors of the chain (terminal operators, shippers, freight forwarders, rail operators and so on). In terms of external costs, the major undesired outcome of this becomes apparent in road traffic congestion, noise and pollution, frequent road accidents and conflict-prone city-port relationships. As a matter of fact, only a few major seaports can have a long and deep river for barging at their disposal. On the contrary, rail is a powerful means of transport, potentially available in most ports and capable of shipping enormous volumes of maritime containers. (see Parola and Sciomachen (2009), Notteboom (2001) as well as Notteboom and Rodrigue (2004)).

It can be stated that the current situation along the freight transportation chain is characterized by strong individualism, where the involved actors focus on independent interests, trying to organize their separate business. In this field, road transport has many advantages, as this is the more flexible between the transport modes. Another option could be the better organization of logistic solutions in order to combine the advantages of more than one means of transport. Thus, the flexibility of the truck could be combined with the capacity of railways or the low energy consumption of inland waterways. However, this option would need considerable effort, as the new system would require investments in infrastructure, equipment, communications, plus a strong will for coordination and co-operation. In the latter case, the highest consideration should be given on the nodes of the system (especially ports), where the most critical part of the transportation (transhipments) would take place.

20.4 The Links: Rail Corridors and Inland Waterways

This part of the document focuses on the issue of transport corridors, particularly focusing on the railway corridors and the inland waterways. It is very important to show the importance that certain actions related to strengthening the corridors might have for the efficiency of transport business. More specifically, this paper attempts to underline the advantages of having better usage of rail and inland waterway corridors in coordination with maritime transport.

20.4.1 The Transport Corridors Concept

The concept of a transport corridor can in practice become operational through some of its main characteristics:

- Canalization of transport
- Concentration of transport volumes

The terms intermodality, multimodality and interoperability receive a special meaning when referring to transport corridors. More specifically:

- "Intermodality" which refers to the combination of several transport modes (road, rail, sea and air) in a way that allows the use of at least two different transport modes for at least one single 'origin-destination-trip'. The concept presupposes the existence of a certain transport node, which allows the transfer between at least two different transport modes.
- "Multimodality" which refers to a characteristic of a transport network in which at least two modes compete for taking trips within the same corridor. It implies that competition exists between transport modes along the same corridor, with the scope to achieve an optimal modal split.
- "Interoperability" which refers to the quality of interaction between two or more transport systems. It is the ability of transport systems to offer harmonized interfaces and an acceptable level of service by intermodal transport for the route, node or corridor under consideration and/or the use of the same mode services provided by different operations/actors. Interoperability is mainly dealing with organizational issues (especially for ports and terminals), as well as the assessment and reduction of any kind of barriers (*e.g.* institutional, financial, physical, technical, cultural, political, etc.)

In transportation planning, contrary to the so-called network approach, the corridor approach is a rather short- and medium-term approach, mainly market oriented. Its aim is to satisfy the existing traffic needs by improving the global services, using existing or upgraded infrastructure (see Dionelis et al (2008)).

In the European policy, the Trans-European Network concept encourages the establishment of a multimodal network as the ultimate policy objective. While certainly appropriate in the beginning, the adequacy of this policy became progressively weaker with the subsequent enlargements of the EU (mainly due to cost limitations). Recently, the European Commission has started to pay more and more attention to the transport corridor concept. Corridor approaches might cover significant needs without enormous investments in the short-term (see COM (2009c)).

20.4.2 Railway Corridors

Railways, although declined significantly from the 1970s until recent years, can make a significant contribution to the construction of an efficient and sustainable European transport system, as surveys suggest that the movement of a container for more than 450 km by rail is preferable to road transport (see COM (2007c), p. 4). In the last decade, its share declined by 1.5 p.a. in EU-27 and by 1.7 in EU-25. Figure 20.1 illustrates this situation.

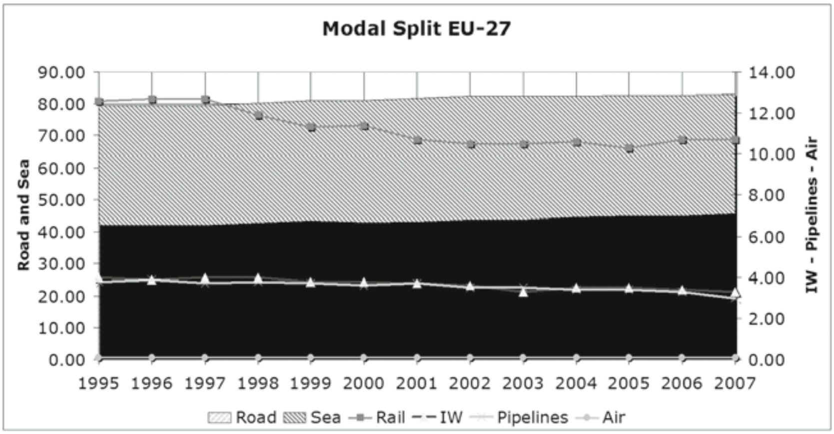

Fig. 20.1 Modal Split EU-27 (see COM (2009a), p. 110)

Rail transport is less costly in environmental terms than road transport and may offer a competitive alternative to the latter on certain major segments of the market. However, it also suffers from major drawbacks:

- The fact that it has to share the infrastructure with passenger traffic,
- Inability to provide door-to-door services, and in most cases lack of connecting lines to production facility sites,
- The lack of interoperability, and
- A culture that is still insufficiently customer-orientated.

Although the above are generally accepted and acknowledged, it is interesting to note the effort of States to separate ‘infrastructure’ and ‘operation’, as well as to privatize a part or the whole of the rail enterprises, seeking higher organizational performance and better financial returns. This trend further contributed to the vicious circle of decreasing available loads for railways, as only profitable connections attracted the interest of pubic and private investors, and other lines, primarily spoke lines, enjoyed decreased maintenance levels and thus offered deteriorated quality of service or were even abandoned. At the same time, road haulers offered flexible and quality service and in combination with modern lean logistics of smaller and more frequent consignments, captivated a major part of the market. In many cases, the struggle for positive short-term financial results jeopardized the attraction of new cargo and also higher turnovers.

Over the last 15 years, the European Community has launched a series of initiatives aimed at revitalizing rail freight transport and giving it a more European dimension, concerning both the way in which the sector is organized (rail freight has been gradually opened up to competition, and has been totally opened up to competition since 2007) and the development of technical interoperability as well as the construction of key infrastructures for the continent of Europe through the TEN-T programme. The idea of TEN-T emerged at the end of the 1980s in connection with the proposed integrated single market. It is believed that it makes little sense to discuss an integrated market, with freedom of movement for goods, persons, and services, without providing transportation networks that link the regions making up that market. Construction of this network will help spur economic growth and employment. The complete concept of the TEN-T is described in the Decision of the European Parliament and the Council No 1692/96/EC on Community guidelines for the development of the TEN-T and its amendments, *i.e.* Decision No 1346/2001/EC and Decision No 884/2004/EC.

The European Commission published a Communication entitled "The EU freight transport agenda: Boosting efficiency, integration and sustainability of freight transport in Europe" which was accompanied by five policy initiatives (see COM (2007a)). In the same line, the Commission presented a communication on a "Freight-Oriented Railway Network" that aims to boost Europe's declining rail sector by tackling efficiency, reliability and competitiveness problems (see COM (2007b)). These initiatives aimed at making the transport of goods by rail and shipping more attractive, in hopes of relieving Europe's increasingly congested roads. The EU executives hope that such measures, along with increased co-operation between member states and infrastructure managers, will help to establish genuine "freight-oriented corridors" capable of competing with road transport for heavy loads and long distances.

According to Transport Commission the aim of latest EU initiatives in the field of freight transportation is to establish international rail corridors, providing operators with an efficient, high-quality freight transport infrastructure to make rail a more attractive option for long-distance freight transport (see EurActiv (2008)). The proposed measures include:

- Increased interoperability
- More investments in infrastructure, terminals and equipment
- Creation of "one-stop shops" for requests for international train routes, defining priority freight for the transportation of time-sensitive goods

The whole effort complements a process already underway to deploy a *E*uropean *R*ail *T*raffic *M*anagement *S*ystem (ERTMS), which aims to replace various national train control and command systems and create common European signaling standards, allowing trains to cross borders without stopping (see COM (2005)).

Evidently, European policy-makers are aware that these proposals are only part of the response to the need to revitalize rail freight, and by no means to consist of a panacea. Incumbent undertakings should be restructured, efficient and effective competition should be restored or established, and grater innovation in the sector should be applied, as new managerial models should be implemented, taking into account the requirements of modern logistics, towards the re-dynamization of a sector that Europe needs.

20.4.3 Inland Waterway

Together with rail and short sea shipping, inland waterway transport is considered to be a mode of transport, which can contribute to sustainable mobility and help improve the sustainability of the transport system. As a barge of 1,500 ton payload is equivalent to 57 lorries (of an average payload of 26 ton), then on the basis of ton-kilometer criterion, inland waterway transport is extremely energy-efficient and is regarded as one of the most environmentally friendly and safest modes of transport. There are more than 35,000 km of inland waterways in the EU, crossing 20 out of the 27 Member States. The modal share of inland waterway transport currently accounts almost 3,7% of the total and almost 7% of total inland transport. In the hinterland of the largest seaports, the modal share of inland waterway transport can reach up to 30%, as is the case of the Port of Rotterdam (see PoR (2009), p. 10).

In line with the objectives set out in the EC White Paper, the intention is to promote and improve the competitiveness of inland waterway transport in the freight sector (see COM (2001)). The aim is to achieve further and better integration of inland waterway transport into the intermodal logistics chain. This can be done if the Union creates the technical, legal and economic prerequisites for optimal integration of various modes of transport for a door-to-door service. In this context, the European Commission has taken various serious measures for the promotion of inland waterways. From these measures the following are mentioned:

- Council Regulation (EC) No 1356/96 of 8 July 1996 set out the rules for market access for international goods transport. Since 1 January 2000, the inland waterway transport market has been regarded as fully liberalized.
- Council Directive 96/75/EC of 19 November 1996 introduced a system of free chartering and pricing, thus ending the system of minimum compulsory tariffs from 1 January 2000.
- Council Regulation (EEC) No 3921/91 of 16 December 1991 set out the rules concerning cabotage, and harmonized the conditions for obtaining boatmasters' certificates
- Special reference is made to Directive 2005/44/EC of the European Parliament and of the Council of 7 September 2005. This Directive refers to harmonized *R*iver *I*nformation *S*ervices (RIS) on inland waterways within the Community

> and provides a comprehensive framework for the establishment and further development of a harmonized, interoperable RIS on the Community's inland waterways. The Directive imposes an obligation on those Member States through which certain Community inland waterways flow to establish these information services in line with the principles and specifications set forth in the Directive. The technical specifications should be developed within a specific timeframe. With these interoperable information services based on modern information and communications technology, the aim is to integrate inland waterway transport more effectively into the intermodal logistics chain. Among other things, RIS will provide fairway and traffic information as well as strategic traffic information for time and journey planning. The system also opens up new opportunities for better freight and fleet management.

In 2006, the Commission proposed a multi-annual Integrated European Action Programme for Inland Waterway Transport "NAIADES" (see COM (2006a)). It recommends action to be taken between 2006–2013 with the aim of fully exploiting the market potential of inland navigation and deploying the ample free capacities of inland waterway transport more effectively. The Programme provides for numerous legislative, coordination and support measures, and focuses on five strategic areas:

1. Creating favorable conditions for services and the development of new markets. This includes:
   - Testing and introduction of new logistical concepts,
   - Supporting scheduled services for intermodal transport,
   - Facilitating access to capital for SMEs, and
   - Improving the administrative and regulatory framework.
2. Incentives for the modernization of the fleet, *e.g.* by developing and promoting the use of innovative concepts and technologies for the construction of new vessels.
3. Measures to address the skills shortage, *e.g.* by improving working and social conditions, greater mutual recognition of qualifications, and securing the existence of education and training institutions.
4. Promotion of inland navigation as a successful partner in business, *e.g.* through more intensive publicity work or by setting up and expanding a European IWT promotion and development network.
5. Provision of appropriate infrastructure through the improvement and maintenance of the European waterway network and development of transhipment facilities, and by supporting and coordinating the development and introduction of RIS.

In the context of multimodal transport, it would be worthwhile to mention certain items about inland ports. In the early 1990s, the term "inland port" started appearing in supply chain and logistics reports, particularly those published in the trade press.

Until that point, it had mainly been associated with inland waterway ports. The new definition of inland ports – as clusters of distribution and logistic centers located on a transportation corridor – indicated a different type of operation, mode, and commodity mix. The idea is that some facilities at traditional maritime ports could be duplicated or complemented at inland locations, thus promoting economic development and logistics integration. As Jaržemskis and Vasiliauskas (2007) suggest, there are many different terms used for an inland terminal facility; often the same term is used for different facilities or different terms are used for the same facility. Quoting their text:

- "An Inland Clearance Depot is a common-user inland facility, other than a seaport or an air-port, with public authority status, equipped with fixed installation, and offering services for handling and temporary storage of any kind of goods (including container) carried under customs transit by any applicable mode of inland surface transport, placed under customs control to clear goods for home use, warehousing, temporary admission, re-export, temporary storage for onward transit, and outright export.
- An Inland Container Depot is a common user facility with public authority status, equipped with fixed installations and offering services for handling and temporary storage of import/export stuffed and empty containers.
- An Intermodal Freight Center is a concentration of economically independent companies working in freight transport and supplementing services on a designated area, where a change of transport units between traffic modes can take place.
- An Inland Freight Terminal is any facility, other than a seaport or an airport, operated on a common-user basis, at which cargo in international trade is received or dispatched.
- An Inland Port is located inland, generally far from seaport terminals. It supplies regions with an intermodal terminal or a merging point for traffic modes – rail, air, and truck routes – involved in distributing merchandise that comes from water ports. An inland port usually provides international logistics and distribution services, including freight forwarding, customs brokerages, integrated logistics, and information systems."

Legally, the new definition of inland ports is based on the Decision No. 1346/2001/EC, amending the TEN-T guidelines adopted in 1996 as regards seaports, inland ports and intermodal terminals. The Decision includes a more focused definition of ports and projects of common interest related to them. Inland ports are seen as part of the network, in particular as points of interconnection between the inland waterways and other modes of transport. The Decision states that interconnection points, including seaports, inland ports and intermodal terminals, are a pre-condition for the integration of the different transport modes in a multimodal network.

These facilities would then reduce the demand on limited seaport capacity (land and access), port-area land values, and the size restrictions of adjacent warehousing and distribution facilities, while increasing the opportunity for their shippers to link with larger, out-of-state modern distribution locations providing a variety of value-added services.

In addition to international trade processing, a crucial role of an inland port is to relieve congestion at borders and traditional maritime ports. Providing consolidated services at one location makes an inland port more attractive to shippers and logistics managers concerned with promoting efficient supply chains. The dry port concept can help identify ways of shifting freight volumes from road to more energy-efficient traffic modes that are less harmful to the environment, relieve seaport cities from some congestion and facilitate improved logistics solutions for shippers (see Roso et al (2008)). Figure 20.2 illustrates the existing situation.

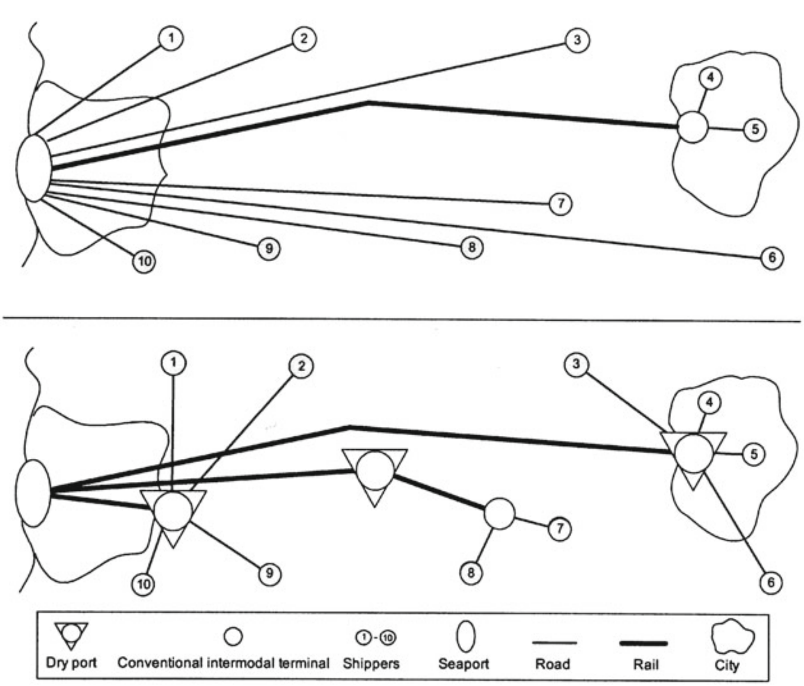

Fig. 20.2 Comparison between conventional hinterland transport and an implemented dry port concept (see Roso et al (2008))

Figure 20.2 from Roso et al (2008) suggests that a combination of the three types of dry ports, the seaport and its surrounding city can be relieved of all road connections to locations outside the city area. In the example the shippers closest to the port (1, 2, 9 and 10) call at the close dry port, two at medium distances (7 and 8) call at the mid-range dry port through another intermodal terminal while the shippers furthest away from the port (3–6) use the distant dry port. As per the analysis of the authors, previously only the shippers very close to the distant conventional intermodal terminal used rail services. Such ideas and combinations may be introduced in order to canalize cargo, as both rail and inland waterways connections envisage high volumes in order to be financially viable and logistically rational. In Jaržemskis and Vasiliauskas (2007) interested readers may find more details on an analysis of opinions solicited in Northern Europe on the advantages of these facilities (see Figure 20.3); one should note the high impact of these facilities in promoting intermodality:

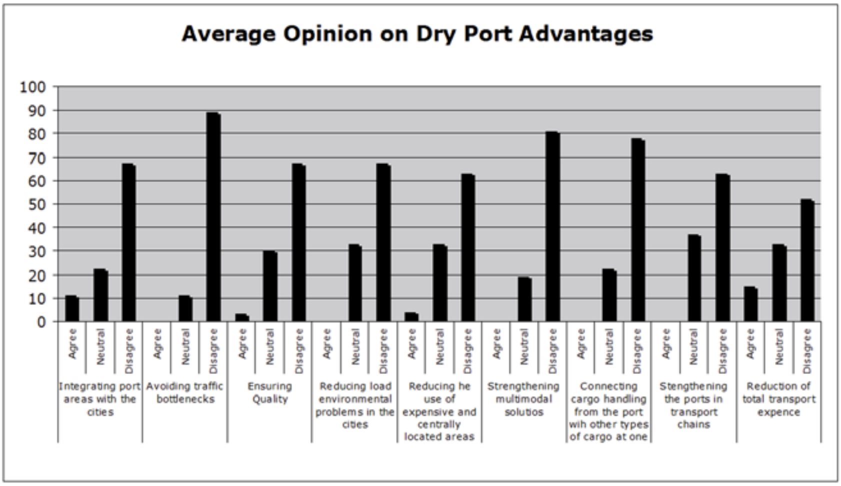

Fig. 20.3 Average opinions on dry ports (see Jaržemskis and Vasiliauskas (2007), p. 211)

As an example of good practice, in Alameda (Los Angeles, USA) a dedicated rail corridor (even if on a small scale – 35 km) aims to de-congest Los Angeles and Long Beach ports, connecting them to a main rail hub with a shuttle train every 29 min; 50 trains per day (with a capacity of 150 trains per day) serve the link. In 2006, 20,000 trains (whereby each train is 1,500 m long and transport of double stack containers is possible) were deployed. This is a concept similar to the "Betuwelijn", a double track rail link connecting Rotterdam and Germany, the latter being on a longer itinerary but still to reach cruise speed. These rail hubs are inland dry ports canalizing cargoes and enhancing co-modality.[9]

The potential for increasing the modal share of inland waterway transport in Europe is significant. More than 37,000 km of waterways connect hundreds of cities and industrial regions. Some 20 out of 27 Member States have inland waterways, 12 of which have an interconnected waterway networks. The existing conditions (scarcity of road infrastructure, environmental considerations, energy needs) and

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[9] The concept of co-modality has been promoted by European Commission from the Lisbon Agenda to define an approach of the universality of the transport modes and of their combinations, as a way to guarantee the growth of competitiveness in Europe in a sustainable manner. It can be suggested that co-modality indicates the approach, while on the other hand, intermodality shows the result.

the specific characteristics of the mode (reliability, low environmental impact and major capacity for increased exploitation) would suggest that inland waterways have very positive chances to succeed in the near future.

20.4.4 Policies for the Co-operation of Maritime Transport, Railways and Inland Waterways

Seeking for more efficient supply chains, the European Commission has taken many measures that could significantly promote the co-operation, synchronization and positive synergies between maritime transport, railways and inland waterways. Among them, the following measures are mentioned (it should be emphasized that the most of the times the measures were accompanied by specific financial aid):

- Marco Polo Programme (Regulation (EC) No 1382/2003), for the period 2003–2006. Aim of the programme was to shift international road freight traffic to short sea shipping, rail and inland waterways as well as to promote innovative projects.
- Marco Polo II programme (Regulation (EC) No 1692/2006), for the period 2007–2013.
- Proposed Directive on intermodal loading units: It aims to create new uniform technical norms for a European intermodal loading unit, which can be used in all modes of transport. This would greatly simplify the process of transhipment and make intermodal transport more competitive (see COM (2003)).
- Communication on freight transport logistics in Europe – the key to sustainable mobility (see COM (2006c)). It defines a strategy to improve the framework conditions in which to increase the efficiency of individual modes of transport and their combinations.
- The publication of the Green Paper (see COM (2009c)), which is a policy instrument, initiates a broad review process of the TEN-T policy. It considers future political and economical challenges such as the achievement of climate change objectives, further economic growth, economic and social cohesion as well as the strengthening of Europe’s international role.

European decision makers have also recognized the importance of logistics. There is also a shared perception that efficiency as well as the sustainability of the logistics industry cannot be taken for granted. A number of factors are converging to put pressure on the transport-related costs of logistics services in Europe and to threaten the sustainability of the practices of the logistics and freight transport industries.

The growing share of logistics in the economy means that these trends may have widespread repercussions for European competitiveness. A second aspect of concern in the evolution of logistics is its environmental impact and specifically its contribution to greenhouse gas emissions. At a time when the environmental performance of many industries is improving, the transport-related emissions of CO_2, of which one third is attributed to freight transport, are increasing and could jeopardize the EU's greenhouse gas emission targets. This trend is clearly not sustainable and needs to be re-assessed. Therefore, the co-operation of environmentally 'friendlier' modes may not be only passively promoted, but must also indirectly 'enforced' through 'environmental taxation' or similar measurements, based on the 'user pays principle', where the term "user" is in this case a synonym of 'polluter'. Both trends, the economic and the environmental, call for the mobilization of actors and resources that could promote efficiency in logistics in order to make more judicious and more effective use of freight transport operations.

20.4.5 Still Existing Problems

Beside the many positive aspects that are expressed in the mentioned political initiatives for strengthening port capacity as well as railway and inland waterway performance, in order to promote global intermodal transport effectiveness, there are still serious problems and inefficiencies that need further actions. More precisely, the following issues need more than good political will and focus:

- Problems related to ports
  - European ports face many and varied challenges. Maritime traffic growth demands better port facilities.
  - Expansion of ports has not kept pace with capacity needs.
  - In spite of decentralization and increased financial autonomy, diverse approaches to port financing in Member States exist: differing levels of financial autonomy and provision of public financing; lack of transparency in tariff setting.

- Problems related to railways and inland waterways
  - An important growth of freight transport can be expected for the coming years. Railways and inland waterways modes in their present situation cannot accommodate this growth.
  - The strong imbalance in the modal split between the different transport modes in inland freight transport, headed by road, would deserve an attempt to re-equilibrate this situation, using each mode at its best potential and in combination with the others ("co-modality") to give a suitable answer to questions regarding the environmental impact of transport, the scarcity of fossil fuels and other negative external effects produced by freight transport and in particular by road.
  - Each transport mode suffers of specific problems, all together hampering the development of real co-modality.

        - *Rail*: lack of reliability due to several factors such as weak coordination of infrastructure managers, scarce interconnection of IT systems, lack of a customer-oriented approach, poor maintenance or delivered quality of service as well as lack of interest or focus to revitalize many abandoned connections to production sites.
        - *Inland waterways*: integration in multimodal transport chains / transhipment facilities;

- Problems related to spatial planning
    - Transport flows across the EU can appear irrational. Freight is often transported to the end user by road from ports located far away, while there are ports in the vicinity. Cost related to currently favored maritime routes from the Far East to Northern European ports alternative routes should be calculated, as an example, to the Mediterranean ports closer to the final destination of the goods.
    - Alternative scenarios with lower transport, external and time-related costs, than the current situation, could be devised. This would call for extended impact assessments when developing major ports. Inefficiencies in hinterland connections would need considerable infrastructure investments. At this stage, the Commission services recommend the “do nothing” option and leave this matter to national and regional authorities.

The 2010 TEN-T mid-term review will evaluate port hinterland connections and their impact on traffic flows. If the set target is, from the total tonnage arriving at the major European ports, in order to increase the traffic share of railways and inland waterways, then one should take into consideration the following basic principles:

- Changes in modal split cannot occur automatically, or by sole political will. The markets and their many involved actors should be convinced that more cargo on wagons or barges does not only mean external benefits, but financial benefits as well. This means that actors should be convinced that if they ”invest” their capital and effort in intermodal solutions, these could result in both financial benefits for businessmen and social benefits for the societies.
- Before taking bigger share at the cargo gateways, railways and inland waterways should first solve their (infrastructure and operational) capacity problems, eliminate bottlenecks and secure customer-oriented policies. Many infrastructure capacity constraints could be overcome not only with heavy investments but also with simple interventions in stations, or in junctions, or using modern signaling technologies, or even via changes in timetables. On the other hand, operational capacity can be considerably extended with increases in speed, better utilization of rolling stock, co-operation between railway enterprises, elimination of delays at borders, etc.
- To succeed in better modal split at the ports vicinity, one should consider the internal problems of the ports. Ports compete within supply chains. Competition has two aspects: Intra-port competition, related to port services, and inter-

port competition between ports in the same market segment. This competition should take forms that will not put constrains to the access of railways and barges to the ports' infrastructure and operation, meaning that any development or political choice, such as concession or privatization of infrastructure, should not deprive other interested parties to have seamless access to the terminals or make use of infrastructure or face unfair competition schemes, such as high tariffs and biased priority grants.

More precisely, it can be understood that seaports are confronted with the sub-optimal functioning of railways and inland waterways. Problems relate to the reliability of these modes, high costs, slowness, and the fact that the rail and inland waterway networks – in general – are not adapted to the needs of the maritime cargo. Ports experience the negative consequences of a lack of sufficient connections, of priority treatment of passengers' traffic and cross-border problems for trains, partly due to differences in technical standards and requirements throughout the EU. The commercial needs of seaports are sometimes not answered in time due to the poorly functioning management of railway and inland waterway undertakings.

One last point of concern is the estimation of the market potential and the feasibility of shifting cargoes from road to other modes, thus increasing the sea-rail and sea-river flows. Given the data of (see COM (2009a), p. 108) of billion ton-km breakdown per mode, the following statistics are available (20.4):

Table 20.4 Modal split in freight transport (in billion ton-km); based on COM (2009a), p. 108

Date	Road	Rail	IW	Pipelines	Sea	Air	Total
1995	1,289	386	122	115	1,150	2.0	3,064
1996	1,303	392	120	119	1,162	2.1	3,098
1997	1,352	410	128	118	1,205	2.3	3,215
1998	1,414	393	131	125	1,243	2.4	3,308
1999	1,470	384	129	124	1,288	2.5	3,398
2000	1,556	386	133	132	1,400	2.7	3,610
2002	1,606	384	132	128	1,415	2.6	3,668
2003	1,625	392	124	130	1,444	2.6	3,718
2004	1,747	416	137	132	1,485	2.8	3,920
2005	1,800	414	139	136	1,520	2.9	4,012
2006	1,855	440	139	135	1,548	3.0	4,120
2007	1,927	452	141	129	1,575	3.1	4,227
% ('95)	42.0%	13.0%	4.0%	4.0%	38.0%	0.0%	??
% ('07)	46.0%	11.0%	3.0%	3.0%	37.0%	0.0%	??
% ('95-'07)	49.5%	17.1%	15,6%	12.2%	37,0%	55,0%	38,0%
% (Annual growth)	3.4%	1.3%	1,2%	1.0%	2,7%	3,7%	2,7%

On the basis of these data, it is obvious that road is increasing with an annual rate of 3.4%, thus 42% of 1995 market share is enlarged to 46% in 2007. Also sea is growing at 2.7%, but its share is relatively constant around 37%–38%. However, rail and inland waterways are loosing market shares, as their rate of increase is lower than that of the total. Simple statistics (and also the graph of the above data) suggest that the time-series of 'total', 'road' and 'sea' may easily be extrapolated by using linear regression techniques. By estimating the market on this basis (although the linear fit seems not to be the appropriate for 'rail' and 'inland waterways', as the resulting r^2 is close to 0.6, in contrast to the over 0.9 for the other series), the following figures are derived for the target years of 2010, 2015 and 2020 (see Table 20.4).[10]

Table 20.5 Estimation for future freight modal split (in billion ton-km)

Date	Road	Rail	IW	Pipelines	Sea	Air	Total
2010	2,060	440	144	140	1.706	3.3	4,494
	46%	10%	3%	3%	38%	0%	
2015	2,328	461	151	147	1,892	3.7	4,983
	47%	9%	3%	3%	38%	0%	
2020	2,595	481	158	155	2,079	4.1	5,472
	47%	9%	3%	3%	38%	0%	

The 'do nothing' scenario seems do be far from sustainable, as in 2020 the total ton-km of road will reach 2,595 bn, even if modestly calculated on the basis of the trend-line, and not of experienced annual growth (which would yield a figure close to 2,980 bn ton-km). These extra 668 bn ton-km (= 2,595-1,927) cannot be accommodated on the existent congested road network and logisticians should find other ways of shipping goods as the quality of their services will be deteriorating due to decreased reliability and flexibility of road connections. Based on the above, a scenario without any further scientific basis, suggests the following for the year 2015 if a percentage of road traffic is diverted to rail or to rail and IW (see 20.6):

Table 20.6 Estimation for future freight modal split under certain conditions (in billion ton-km)

Shifted from Road to Rail	**Road**	**Rail**	IW	Pipelines	Sea	Air	Total
1%	**2,305**	**484**	151	147	1,892	4,0	4,983
	46%	**10%**	*3%*	*3%*	*38%*	*0%*	
2%	**2,281**	**507**	151	147	1,892	4	4,983
	46%	**10%**	*3%*	*3%*	*38%*	*0%*	
5%	**2,211**	**577**	151	147	1,892	4	4,983
	44%	**12%**	*3%*	*3%*	*38%*	*0%*	

In this scenario, cargos shifted from road to rail, *i.e.* 1%, 2% or 5% of the total road ton-km, suggest new loads (in terms of bn-km) of 5%, 10% and 25% for the

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[10] Once a regression model has been constructed, it is important to confirm the goodness of fit, in other words, how well the model fits a set of observation. A commonly used check of goodness of linear fit includes the r-squared test, r^2, where an r^2 of 1.0 indicates that the regression line perfectly fits the data, *i.e.* the model explains perfectly the trend.

rail network, over and above the existing and expected loads, given the available statistics. In terms of ton-km, these new loads are not impressive for the road, as they do not exceed 23.47 and 116 bn for a shift of 1%, 2% or 5% respectively. For the rail operators, these figures may be very optimistic though not unmanageable. This scenario provides the figures shown in Table 20.7.

Table 20.7 Estimation for future freight modal split under certain conditions (in billion ton-km)

Shifted from Road to Rail and IW	**Road**	**Rail**	**IW**	Pipelines	Sea	Air	Total
2%	**2,281**	**484**	**175**	147	1,892	4.0	4,983
	46%	**10%**	**4%**	*3%*	*38%*	*0%*	
4%	**2,235**	**507**	**198**	147	1,892	4	4,983
	45%	**10%**	**4%**	*3%*	*38%*	*0%*	
6%	**2,188**	**530**	**221**	147	1,892	4	4,983
	44%	**11%**	**4%**	*3%*	*38%*	*0%*	

Following the above idea, a percentage of 2%, 4% and 5% of road ton-km are shifted to rail and inland waterways equally. In this situation, rail should serve 5%, 10%, and 15% more cargoes, shifted from road to rail. As above, the figures are optimistic, there seems to be capacity, yet in terms of road network relief the impact is limited. In contrast, the figures for the inland waterways suggest 15%, 31% and 46% respectively, new loads shifted from road to IW over and above the existing and expected ones. This scenario seems very optimistic, and as in the case of rail, the real limitation is not the capacity of the network but the market structure, the business culture and the terminal interfaces.

Briefly, the estimation of the market potential as well as the capability of rail and inland waterways to undertake adequate loads (in terms of ton-km) is also an issue that planners should take into account. One should consider the political will and congestion of road networks, which will definitely trigger the interest of logisticians to intermodal or co-modal solutions on the one hand, and on the other, hand the actual capabilities of rail and inland waterways operators to handle from a business point of view the shifted loads.

Obviously, the EU actions are geared towards the right direction. From a pure financial viewpoint, the need to press for intermodality is not an obvious option. However, from a political viewpoint it is crucial to take into consideration the need for sustainability and to foresee future problems regarding (*e.g.*) capacities. As it often happens, the challenge is not simply to choose one alternative, but to combine the alternatives and to take measures on time. Thus, the social benefits will be ensured, without major market risks.

20.5 Insights and Recommendations for Terminal Planners and Operators

Given the analysis and the above points, what could one recommend for terminal planners and operators? To this rhetoric question, one should take into account the following points that may determine the answer:

- Terminals are only means of modern logistics that aim at satisfying the request for physical flows (goods, transport, packaging, storage etc.) and for associated information flows (traceability concept). It is in charge of managing the means making it possible to achieve this objective and mobilize resources (human and financial) to this end. As transport constitutes one of the main pillars of logistics (the others being processes and storage), it is therefore central to the co-modality concept and to its promotion. In summary, the 'global efficiency' of a terminal is a prerequisite for users, who may select logistics chains via this terminal, instead of others at inter- or even intra-port level of competition.
- A 'global efficient' terminal shall enjoy agile and advanced hinterland connections. Infrastructure problems, considered either as issues of congestion and limited capacity or as interoperability and intermodal interface issues, jeopardize logistics flow and wreck the attractiveness of the terminal as a nodal point. Therefore, terminal operators should seek solutions at business or political level, as appropriate, for the mitigation of such problems in the targeted hinterland. Furthermore, active marketing from the terminal side requires continuous monitoring of infrastructure advancements in the hinterland or neighboring regions, and proposal of new logistics alternatives to the users, as well as active participation in related projects (of vertical or horizontal approach). The issue of active marketing and agile managerial response to challenges is also an issue closely linked with the management and corporate model.
- Efficient hinterland connections and available infrastructure may not be a possible short- or even mid-term goal, due to various local parameters. The least a port can offer though, is open spaces at the vicinity of the port, where FTZ or port clusters may evolve, resulting on higher volumes and higher socio-economic importance. Higher freight volumes justify infrastructure investments and stakeholders may exercise pressure on decision-makers on the basis of high figures. The socio-economic importance of a port (or of a region) may also attract the interest of policy makers, as employment and social cohesion are of prime interest, and indirectly exercise pressure for advancements in infrastructure..
- Energy efficiency and environmental friendliness of the logistics chains shall be taken into account when designing physical flows of the future. Rising traffic volumes on the European transport network need to be accommodated and sustainability becomes an issue. A correct quantification of the present and future freight traffic fluxes and their relation with supporting infrastructures is essential to identify the major European transport corridors for the coming years.

This will consist in identifying concentrations of freight traffic between major poles, where a concerted intervention could allow the implementation of an integrated transport concept in which each mode is used according to its comparative advantages (co-modality concept = effective use of different transport modes isolated or in combination in order to obtain an optimal and sustainable utilization of resources). The Logistics Action Plan indicates the need by 2020 to define the ”green corridors” and to reinforce their importance and role in the TEN-T priorities. The green corridors, whose definition is addressed by research actions under preparation, should allow the transfer of massive freight traffic fluxes among several hubs on a 24/7 basis (conveyor style) optimizing the use of the assets and the efficiency of the logistics chain whilst minimizing external impacts (safety, congestion, noise, pollution).

- Considering that the market potential exists, although not fully quantified, terminal planners and operators should take into account the contracting set of goals; policy-makers will promote sea-rail and sea-river options either by penalizing road movements or by investing in new infrastructure or both, while rail and inland waterways operators may not be ready to undertake such loads. This may also lead to increased dwell time for cargoes waiting at the terminal to be forwarded to the hinterland, and deterioration of the logistics service quality. A chain of terminals, such as of sea-ports and inland ports, may be the answer for canalizing higher volumes of traffic and keeping the quality of logistics services at adequate levels. Finally, this may suggest closer managerial or operational ties among terminals and transport providers.

It is also mentioned that environmental aspects become more and more important in bidding processes regarding multimodality in transport operations. In this context, large projects (public, private, concessions) regarding container terminals must respect the strict European rules for sustainability. Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment is the main document setting the rules in this respect.

The planning gateway problems attract gradually the attention of the academic and professional community, and until today, the idea of inland ports and canalization of loads seems rational and achievable. The drawback is the slow pace of implementing policies a result of the complexity of these projects and of the various interests represented by stakeholders. Despite the problems it becomes evident that terminal planners and operators should expand their interests far from the terminal, to the hinterland and to the efficiency of the logistics connections linking the terminal with existing and potential customers.

20.6 Conclusions

The paper has discussed some main points regarding sea-rail and sea-river connections, mostly focusing on the EU policies on these issues. The paper presented the issues of maritime logistics and intermodality, showing that whereas internationally, maritime has always been the most important means for transport, intermodal transport logistics has started to be a key policy element in the last 15–20 years. Especially in the EU, this has been expressed with concrete political actions that aim at strengthening intermodality. To achieve this task, attention should be given to the whole transportation chain, *i.e.* to nodes (especially ports) and to links (corridors). The concept of intermodality is directly linked with the shift of freight traffic volumes from road to other transport means (railways and inland waterways). This is an obvious result of the scarcity of road capacity and the better environmental performance of the other modes in comparison to road. The main conclusions of this paper can be outlined as follows:

- The need for strengthening intermodality is widely accepted. Strengthening railways and inland waterways as well as trying for better feeder operations at ports are key elements in this effort.
- EU has taken many initiatives towards this direction. Even if the results are still poor (road transport is still by far the dominant transport mode), the expressed clear political view that the EU will continue to support intermodality has a strong value. The actors in the market should take this clear policy into consideration and should try to contribute and benefit from this policy.
- The potential of intermodal freight transportation is strong. Many large projects for the modernization of railways, inland waterways, seaports, inland ports and terminals have been put on. In the context of the TEN-T development, EU has secured the financing for these projects.
- The various actors in the market should realize the need for co-operation, as this is the main prerequisite for success.
- There are still many problems and obstacles to overcome, but it should become clear that intermodality could be a positive business field for the market, and a concrete step for sustainable development from society's point of view.

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