Abandoning the Spherical Container Terminal

The support of container terminal berth planning by the integration and visualization of terminal information

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T B A SIMULATION EMULATION SOFTWARE

Faculty of Technology, Policy and Management

June 2011



From Wikipedia:

Spherical Cow is a metaphor for highly simplified scientific models of reality. The phrase comes from a joke about theoretical physicists:

Milk production at a dairy farm was low so the farmer wrote to the local university, asking help from academia. A multidisciplinary team of professors was assembled, headed by a theoretical physicist, and two weeks of intensive on-site investigation took place. The scholars then returned to the university, notebooks crammed with data, where the task of writing the report was left to the team leader. Shortly thereafter the farmer received the write-up, and opened it to read on the first line: "Consider a spherical cow in a vacuum...."

Abstract

Containerized transport has shown a considerable growth ever since its inception. Ever-increasing volumes and vessel sizes put considerable pressure on terminals trying to maintain their service levels. Keeping up with growth provides many terminals worldwide with a considerable challenge. One way to meet this challenge would be to improve terminal planning. Many planning decisions have to be taken at terminals. This research will focus on berth planning. The main goal of berth planning is to assign all vessels a mooring spot in such a way that contractual obligations are fulfilled, but at the same time in such a way that the costs for the terminal will be as low as possible.

This research was conducted at TBA, a consultancy company specializing in container terminals. In TBA experience, this berth planning process heavily depends on all kinds of information, but terminals often have difficulties in managing this information flow and IT support is often low. Furthermore, planning has to overcome issues relating to the uncertainty present in the terminal's environment. Therefore, the goal of this research was to establish *what kind of decision support tool should be designed to improve container terminal berth planning and the handling of information required to make such plans, and what prototype of such a tool can be designed.*

A number of steps have been taken to arrive to a working prototype. First, the role of berth planning in terminal operations and the current state of affairs was analyzed, resulting in the identification of opportunities and challenges in container terminal berth planning. Based on these, the current approaches for providing decision support were discussed. Virtually all currently published research stems from an Operations Research background. Although a lot of research has been published, matching these approaches with the problem analysis has shown that these approaches have failed to fully capture the dynamic nature of real life terminal operations. These approaches have consequently had little impact in practice as of yet.

As it was argued based on the current approaches that a fully automated planning solution is not yet feasible, this project focused on the creation of a more interactive tool. Existing research and ideas that supports such approaches was combined with the problem analysis in order to establish a set of ten highlevel design principles for a container terminal berth planning tool. Based on these principles, a functioning prototype was created that can be used to visualize the various information relevant for the plans, and enables the planners to interact with this information. This was done in such a way that it allows them to not only explore the information, but also to explore various possible decision alternatives and their consequences.

This prototype was evaluated in a workshop with TBA staff. While a more rigorous evaluation would be preferred, the evaluation carried out now gave strong indications that the participants had a better experience and performed better compared to a more traditional Excel-based approach. Furthermore, the prototype has been well-received by a number of TBA customers and the possibilities for implementing the prototype at a terminal are under investigation. It can be concluded that an interactive approach to berth planning decision support seems very promising and deserves more research attention.

Delft, June 17 2011

Preface

Some time ago, my graduation committee was discussing the past course of my graduation project. During this discussion, they referred to it as a 'Brownian motion', similar to the movement a billiard ball makes on the game table. This is a very accurate description of my graduation project: as I was trying to move forward, some of my paths later turned out to be sidetracks. Conversely, some sidepaths turned out to be very fruitful avenues. The main example would be the construction of the berth planning tool; when I started programming I had not expected myself to take it this far. This Brownian motion also had consequences: I had kept on exploring so many new research directions that turning my thesis into a coherent story proved to be quite a challenge that I am now happy to complete by writing some last words of thanks.

Taking this metaphor to the next level, I have been very lucky during this project to have had my graduation committee to act as the table bounds if it were, making sure that I did not stray completely off-table, bouncing me back while trying to retain as much of my energy as possible. Mieke, thank you for providing different perspectives when I needed them. Scott, thanks for always having new and interesting suggestions ready. Job, your endless interest in my ponderings about the project has never ceased to amaze me. Thanks for that and the many enjoyable hours we spent discussing. Finally, Alexander, I feel honored to graduate with you as my professor, you have made it an inspiring time! Thank you for your enthusiasm!

While drifting across the table I also encountered other balls to ricochet off from, pushing me in a new angle, accelerating my momentum. Many people were willing to discuss my project or help me in other ways. First of all, I would like to thank the staff at the terminals I visited for showing me around and making me more familiar with the topic. Jaap, Richard and Cissy at APMT Rotterdam, and Ivo, Claudia, Fons and Werner at MSC Home Terminal, thank you very much!

My colleagues at TBA have provided me with a very comfortable atmosphere to conduct my work, and several of them took the time - especially in the beginning of the project - to discuss the container terminal industry with me. Pascal, Csaba, Martijn, Jeroen, Remmelt, Santhana, William and Rohit, thank you! Furthermore, I would like to thank Aad, Pascal & Pascal, Rienk, Age, Carla, Roel, Ron and Willem Jan for taking the time to participate in my workshop. Finally, this project was very much driven by Yvo's vision as well. Yvo, thanks for giving me the opportunity to do my project at TBA!

Finally, several people at TU Delft have taken the time to discuss my project with me, especially when I strayed into unfamiliar territory and required some help. Tjerk de Greef at MMI, Arnold Vermeeren at ID, and Wim Veen, Linda van Veen, Michele Fumarola, Mamadou Seck, Nitesh Bharosa and Pieter Bots at TPM, thank you! And Ronald Poelman, thank you for helping me create the cover image!

In addition to the people involved in my project, I would like to thank the TBM staff and fellow students for providing me with a great time while I was studying in Delft, and my bandmates for not complaining too often about my spending time on other things so much during the past months.

Most importantly, I would like to thank my friends and especially family for giving me their support throughout the years when I needed it. Thank you, it is very much appreciated!

Contents

Abstract Preface Table of Contents							
				1	Rese	earch Formulation and Thesis Overview	1
					1.1	Research questions	2
	1.2	Research methodology	3				
	1.3	Thesis layout	4				
2	The	Container Terminal. An introduction	5				
	2.1	The birth of containerization	6				
	2.2	Growth of container cargo flows	7				
	2.3	The role of the terminal in the container shipping process	8				
	2.4	Developments in liner shipping and their effects on terminals	11				
	2.5	The terminal as a technical system: a closer look on terminal operations	13				
	2.6	Container terminal planning	18				
	2.7	The terminal: operational issues	23				
	2.8	The terminal as a social system	24				
	2.9	The terminal: round-up	25				
3	Prol	plem Analysis: The gap between berth planning in theory and practice	27				
	3.1	Operational demands: the role of berth planning in terminal operations	27				
	3.2	Berth planning: the current process	41				
	3.3	Berth planning: operational aspects	42				
	3.4	Berth planning: organizational aspects	44				
	3.5	Berth planning: opportunities and challenges	48				
	3.6	Problem analysis: round-up	50				
4	Bert	h Planning: Decision support	51				
	4.1	Berth planning in theory: the state of the art in berth planning OR research	51				
	4.2	Consider a spherical terminal: the gap between theory and practice	52				
	4.3	An empirical view: planning as a complex socio-technical system	54				
	4.4	Planning and human decision making	57				

4.5 The way forward: Interactive Decision Support	61			
 5 Intelligence Amplification: Theoretical foundations 5.1 Augmenting human capabilities: man-computer symbiosis 5.2 Early experiences: Decision Support Systems 5.3 Information overload 5.4 The last four inches: visualization of information 5.5 Theoretical foundations: round-up 	63 63 68 70 73 76			
 6 Design Principles 6.1 Exploit the way in which human and computer can add to each others' capabilities	79 80 82 82 83 g			
decisions	. 85			
 7 Prototype Design: Embodying the design principles 7.1 Prototyping: method and motivations 7.2 Functionality selection 7.3 Berth planning prototype: implementing the design principles 7.4 Prototype design: round-up 	87 87 88 91 105			
 8 Principles & Prototype: An evaluation 8.1 Prototype evaluation	107 107 116 118			
9 Conclusions 9.1 Conclusions: research questions revisited 9.2 Recommendations for TBA 9.3 Project and Process Evaluation	119 119 121 122			
Bibliography 125				
A Human decision making: Simon's views A.1 An artificial world: on the design of artifacts A.2 Decision making as a design process A.3 Ill-structured problems A.4 The representation of problems and the simulation of solutions A.5 Criticism A.6 Design Theory: Wrap-up and relevance	135 135 136 138 139 140 140			
 B Visualization Tools B.1 Focus + Context visualization concepts B.2 Time Slider implementation 	143 143			
C Code base: classes and length of code	. 146 149			

D Questionnaire Documentation and Results	151
List of Figures	160
List of Tables	161

Chapter 1

It is sound planning that invariably earns us the outcome we want; without it, even the gods are unlikely to look with favour on our designs.

> Herodotos - *Histories*. Book 8, chapter 60 THEMISTOCLES OF ATHENS

Research Formulation and Thesis Overview

Container terminals are the mainports through which massive flows of containerized goods are shipped from one port to another. Containerized shipping has taken a huge flight since it was introduced over half a century ago. The never ending rise in shipping volumes and vessel sizes put quite a burden on the terminals. The demands on their operations have become bigger, while still having to live up to the same productivity and efficiency standards. This situation has put terminals worldwide to quite a challenge.

Providing a better answer to this challenge will be the objective of this thesis. Previous efforts have discussed on the operational side of terminals (see for example Farré Barberà, 2009; Steenstra, 2009; Hu, 2008), on the technology used (see for example Oya Abajo, 2008; Saanen, 2004; Saanen and Valkengoed, 2005), or on the development of planning algorithms (for an extensive review, see Steenken et al., 2004; Stahlbock and Voß, 2008). This thesis will focus on terminal planning.

There are a number of planning decisions that have to be taken at terminals. Terminals have huge *yards*, where containers are placed. Yard planning then deals with the assignment of locations in the yard for containers. To move containers, both labor and equipment are needed and must thus be planned. Maintaining the equipment has to be done as well, and therefore it must be planned as well. However, this thesis will focus berth planning. When a vessel in the terminal, it will sit alongside the *quay* wall, which is the outer structure of a terminal next to the water. The berth is the place at the quay where a vessel can moor. Berth planning deals with the allocation of vessels to a berth, and often as well with the allocation of a number of *quay cranes* to the vessel, that will lift containers from the quay to the ship and vice versa.

Research problem

The main goal of berth planning is to assign all vessels a spot in such a way that contractual obligations are fulfilled, but at the same time in such a way that the costs for the terminal will be lowest. This process heavily depends on information: information on vessel arrival times, call sizes, labor and equipment availability, the locations of containers in the yard.

This master thesis project was carried out not only at TU Delft, but also at TBA Netherlands. TBA is a consultancy and software development company specializing in maritime container terminals. In TBA experience, many terminals have problems in handling all this information. Often, key information is not present, or it is presented in such a way that planners have little use for it. The level of IT support for the task is often low: at many terminals, the tool used for creating and maintaining these plans is simply a whiteboard, or in some cases a static worksheet in Microsoft Excel.

Furthermore, terminal planning in general has challenges to overcome relating to the uncertainty in their environments. Terminal operations are subject to outdoors environments, to issues of complexity in their large-scale operations, and to the difficulties associated with the human factor: there is much manual labor at terminals. These issues have hardly been described in the existing literature on container terminals.

TBA would be particularly interested to learn more about berth planning and what could be done to improve it, so that they can deliver services to their customers that relate to these issues. The goal for this research is therefore to learn more about berth planning on one hand, and on the other hand about what kind of decision support tool could be used to improve existing operations. This has to be worked out in the form of a working prototype of a berth planning decision support tool.

The knowledge gaps that need to be closed in order to design such a tool are placed on two dimensions. The first relates to berth planning itself; very little has been published about the exact process and challenges at terminals. Secondly, there are knowledge gaps relating to the design of a support tool. These gaps serve as the basis for the research questions that are defined in section 1.1.

1.1 Research questions

The previous section clarified the research scope, by discussing the research problem and objective. Based on this scope, this section will introduce the research questions that will guide the research for this master thesis project. The main research question is defined as follows:

What kind of decision support tool should be designed to improve container terminal berth planning and the handling of information required to make such plans, and what prototype of such a tool can be designed?

In order to answer this question, it is decomposed into two sets of sub questions. The first set deals with *what* should be supported by such a tool; the second set deals with *how* it should be supported. A final sub question deals with the prototyping aspect of the project. The sub questions are defined as follows:

- 1. What is the current state of affairs in container terminal berth planning?
 - (a) What is the role of berth planning in terminal operations?
 - (b) How is container terminal berth planning currently organized and performed?
 - (c) What are the opportunities and challenges?
- 2. What would be a suitable design approach for a berth planning decision support tool?
 - (a) What approaches to berth planning decision support have already been explored and what are their merits?
 - (b) Would another approach to berth planning decision support be more suitable?
 - (c) What kind of design principles can guide the design of a berth planning decision support tool under such an approach?
- 3. What prototype can be developed based on these principles, and how would this prototype assist in berth planning?

1.2 Research methodology

In order to design a tool aimed at the support of container terminal berth planning, a lot of knowledge about terminals will be required. However, there are problems with *scope* and *access*. Access refers to being able to visit terminals in order to gather requirements. While two terminals were visited in the research project two get an impression of the problem, this was nowhere near enough to get a complete picture of the requirements for such a system. Getting such access is cumbersome when nothing exists yet that might be of potential use for a terminal, not even some general ideas. Indeed, scope was badly defined at the start of the project. While berth planning was taken as the subject of choice, and TBA wished for visualization techniques to play a big role in the project, not much else about the scope was determined before hand.

This puts some classic systems development methods at a disadvantage. For example, classic IS design methods such as a waterfall approach depend on being able to define concrete requirements before development starts. With every terminal being different, planners relying on tacit knowledge, and no literature being available on actual berth planning, this is impossible. On the other hand, methods like rapid prototyping rely on swift successions of prototypes that are checked with the future user. This requires a buy-in from terminals that was unattainable at this stage of the project. Furthermore, the time limits on this project meant that completing more than one iteration for a working tool was problematic in itself.

Design approach

For this reason, the only available approach is one where a design is based on desk research. The chosen methodology is based on the regulative design cycle (Van Strien, 1986). The regulative design cycle consists of a number of phases: signalization, analysis, design, try out, and evaluation. This method is a high-level method. To better steer the method into a direction that is suited for this research project, some elements from methods used in the design of human computer interaction systems (Neerincx et al., 2008; Endsley et al., 2003) were added. These elements are at the level of the analysis phase; they structure this phase into an analysis of operational demands, human factors knowledge and a technology analysis.

Other elements from the method described by Neerincx et al. (2008) consist of the definition of a requirements baseline that is linked to each iteration of the prototype. They recommend defining requirements for each version of the prototype that is backed by a design rationale consisting of a set of high-level and abstract core functions, defining a set of testable claims that are linked to these core functions, and testing these based on a set of scenarios and use cases. Considering that only one iteration can be completed in this project, there would be some issues with this approach.

First of all, when the design has to be driven by the evaluation of the requirements baseline, none of the input could be taken along in a second design cycle. Secondly, the baseline has to be linked to the prototype and therefore any insights derived from the analysis that are not taken along in the functionality of the first prototype will be lost. Finally, on a more methodological level, there is no clear definition of the core functions given. There are some examples though, but the abstraction level of the core functions given is rather high. This does not match the abstraction level of a prototype. Consequently, a great number of possible implementations may exist for one and the same core function that have significant differences between them. When the test on the claim comes out negative, this creates problems because it will be unclear whether the core function itself or merely the implementation is to blame.

Design stages

In this project, design is done in a number of stages. First, the problem is studied, available literature is analyzed. Then the ideas gathered in the analyses will be worked into a set of high-level design principles

that can guide the development of an actual prototype. In the final stage, the actual prototype will be created based on these principles. In a way, the prototype design will emerge from the design principles.

The resulting prototype will just be one of many possible implementations of the design principles. Iterations can be made over this prototype while the principles stay the same. It should also be noted that the development of systems like the one proposed here may take years in many cases, and in the mean time the problem analysis may change: new technologies may emerge, new human factors theory may have been put forward or there may have been developments in the application domain. An iteration over the analysis phase should then be done, possibly resulting in a different set of design principles.

The resulting methodology is displayed in fig. 1.1.



Figure 1.1: Overview of research methodology

1.3 Thesis layout

This section will discuss the thesis layout. First, a general introduction into container terminals is given in chapter 2. Then, the focus will be shifted to berth planning in chapter 3. The possible approaches for offering berth planning decision support will be discussed in chapter 4, and the chosen approach will receive further attention in chapter 5. Throughout these chapters, some valuable insights will be marked and worked into one of the design principles presented in chapter 6.

Based on these principles, a prototype was designed. This prototype is discussed in chapter 7 and evaluated in chapter 8. Finally, some conclusions will be made in chapter 9.

Chapter 2

The Container Terminal. An introduction

In today's world, the global economy allows consumers to enjoy products from all around the world. It has become perfectly normal to order a book in The Netherlands from a company based in the US that ships the product from their warehouse in Malaysia. When examining the parts in a laptop computer, one should not be surprised that before a new laptop is taken on a trip, it was already a well-seasoned traveler.¹ It is a complex product with many parts, with almost as many countries of origin. Likewise, the construction of modern-day products often occurs in a series of production steps that are distributed throughout the world. This supply-chain based economy is made possible by cheap and efficient transport of goods around the world. The milestone innovation that enabled cheaper shipping and therefore this supply-chain based economy was the development of containerized shipping (Levinson, 2006). The shipping container celebrated its 50-year anniversary in 2006, and in its present lifetime managed to start a continuous flow of containerized goods around the world that has shown a tremendous growth ever since its inception.

A shipping industry under stress

This tremendous growth however has placed the shipping industry in general, and container terminals in particular, under considerable stress. Due to the rapid increase in shipping volumes, the operations throughout the supply chain have increased in complexity. This complexity has placed tougher demands on container terminals: they need to handle larger volumes and larger peaks in this already increased workload, all the while guaranteeing swift turnaround times for vessels and a sufficient level of efficiency in their operations. They are therefore faced with the challenge to cope with these increasing demands. To meet this challenge, it is essential that terminal operators increase their efficiencies.

Chapter layout

In order to better understand the challenge, this chapter will provide an introduction and put it in a context. First the rise of containerized transport as a logistical concept (section 2.1) and its growth over the years (section 2.2) will be discussed. Then, the role of the terminal in this concept of containerized transport (section 2.3) and the role of the liner shippers section 2.4 will be discussed. The processes at the terminal,

¹http://dylan.tweney.com/writing.php?display=483 - accessed on May 7, 2010

including operational (section 2.5) and planning (section 2.6) processes will be explained. Based on this analysis, it will start to become clear why terminal operations are complex. This complexity will be discussed in more detail in section 2.7. The detailed story laid out in this chapter will then serve as a basis for the problem analysis questions, which will be presented in chapter 3.

2.1 The birth of containerization

In celebration of the shipping container's 50-year anniversary, Levinson (2006) provides an elaborate historical account of the rise of the shipping container. As summarized in Jacob's (2009) review of Levinson's book, containerization was a process that was initially not welcomed by some groups of people: dockworkers and their trade unions heavily opposed the change, while ports feared new investments and loss of demand. The major source of work involved with the shipping of goods before containerization was the process of loading and unloading goods on an item-by-item basis. For this reason, it was also a major source of shipping costs. According to an expert opinion featured in Levinson's book, "a four thousand mile voyage for a shipment might consume 50 percent of its costs in covering just the two ten-mile movements through two ports." (Levinson, 2006, page 10) In contrast, containerized shipping does not require each item to be transferred individually. Instead, an entire container and its contents are transferred in one operation, providing a standardized way of efficiently dealing with this transfer operation.

Resistance against containerization as an enabler for new ports

All this manual handling was obviously a source of work for the longshoremen that composed cargo handling gangs.² When the first container operations were set up, unions responded by strikes. When government invested in London's Tilbury port with the hope that it would become Europe's biggest container port, the unions imposed a ban on container handling which ended up lasting for 27 months. Meanwhile, some private investments were made to the minor port of Felixstowe to make it suitable for container handling. Due to its small size, the unions never bothered to be active there. The investments paid off, and turned this former sleepy town turned into a hub of activity due to being the first large container port in the UK. When the unions in Tilbury saw activity in Felixstowe rising, they lifted their ban. By then Felixstowe had solidified their position as the leading container terminal in the UK. It still holds this position today, and was in fact ranked as the sixth busiest terminal in Europe in 2008.³ Similarly, when the congested docks in Brooklyn, New York faced containerization their response was resistance. The nearby port of New Jersey responded with investment in infrastructure, leading to near-abolishment of the Brooklyn docks as a cargo handling facility.

Development of standards

Eventually, the shipping container managed to overcome this resistance. Dedicated container vessels were built, dedicated container terminals were constructed: containerization set off. Whole ports were constructed based on the container paradigm, with whole economies forming in their wake. The design of specific equipment for lifting and moving containers took off in the early 1980s (Notteboom and Rodrigue, 2008), enabling container terminals to operate with larger throughputs and at higher efficiency. Standards for containerized shipping emerged, most notably in the form of the ISO shipping container. These metal

²For a romanticized picture of these gangs in the Brooklyn docks, see the 1954 classic film *On the Waterfront*, featuring Marlon Brando.

³http://www.worldportsource.com/ports/GBR_Felixstowe_Port_242.php - accessed on May 7, 2010

containers are usually 20 or 40 foot in length; container quantities are often measured in Twenty-Foot Equivalent Units (TEU). A 40-foot container is two TEU or one Forty-Foot Equivalent Unit (FEU).

Based on these standards, standardized handling equipment could be developed. This includes twist locks, which attach a container to other containers or to equipment at each corner of the box. It also includes spreaders, which are elements of container lifting equipment: the spreader is attached to the top of a container to lift it. Nowadays, some spreaders can *twin* two twenty foot containers, enabling faster handling if there are many TEU-sized rather than FEU-sized containers. This is described by the TEU Factor (Saanen, 2004), which is somewhere between one and two.

Economies of scale in container shipping

The key strategic advantage offered by the shipping container are the low cost of transferring the container and its goods from one transporter to another, thereby facilitating cheap transshipment. Rather than sending containers from their origin to destination with as few moves as possible, sending the container to its destination over a number of different segments may be more attractive. Combining containers with as many other containers as possible lowers the costs of shipping. These economy of scale benefits have led to the development of container hubs and spokes (Saanen, 2004): containers are moved in very large quantities between hubs, and sent to their final destination port through a nearby hub on a smaller vessel. Shipping containers has become a matter of managing transportation over a sequence of links.

2.2 Growth of container cargo flows

Especially since the mid-1990s, container volumes are rapidly increasing (Notteboom and Rodrigue, 2008). The amount of shipped containers grew five times from 1988 to 2006 (see fig. 2.1), at an average rate of



Figure 2.1: Increasing container trade scale Source: UNESCAP, 2007

9.5% per year (UNESCAP, 2007). This resulted in shipping companies ordering bigger ships, in pursuit of economies of scale. While vessel sizes have been steadily growing since the seventies, the explosion of container moves in the last decade led to a similar explosion of vessel size during the same period (see fig. 2.1). While the biggest ships ordered in the early nineties were 4000+ TEU vessels, the 10,000 TEU barrier was broken in 2007 (UNESCAP, 2007).

The largest vessels currently in operation are Maersk's PS-series, with an official capacity of 11,000 TEU.⁴ Its actual capacity based on the space available may even be as high as 14,000 TEU⁵: Maersk measures the number of containers a vessel can carry with an average weight of 14 tons per container. Asian export containers generally weigh less.⁶ Similarly, the largest MSC vessels rated at 14,000 can carry only 10,640 TEU with an average container weight of 14 tons.⁷

Some have been discussing the prospects of future vessel sizes to reach as much as 18,000+ TEU (UN-ESCAP, 2007; Imai et al., 2006; Wijnolst, 2000) for quite some time. A study by Van Ham (2005) describes these challenges to be related mostly to whether terminals will be able to cope with these increased call sizes, and to whether shipping companies will be ready to make the changes to their service networks required to make operating vessels of this size profitable. As it seems, the economic situation now is such that Maersk felt it would be profitable to order twenty Malaccamax vessels.⁸

2.3 The role of the terminal in the container shipping process

The previous sections have discussed how containerization came about, and how containerized transport has grown over the years. Now, the port facilities that handle this flow of containerized goods will be discussed: the container terminal. While the next section will discuss the processes at the terminal in more detail, this section focuses on terminals on a more fundamental level. It will discuss the role of the terminal in the container shipping process, by highlighting the functions of the terminal, and developments in its role.

Terminal functions and physical layout

According to Saanen (2004), a container terminal has two functions: the transshipment of containers from one mode of transport to another, and the temporary storage of containers on the terminal yard (see fig. 2.2). Containers enter or leave the terminal at the waterside over the quay by a container ship, and on the landside through the gate by truck, rail or barge (see fig. 2.3). When a container is brought in on the waterside and leaves on the landside, it is an import container. When it is brought in on the landside and leaves on the waterside, it is an export container. In general, when one refers to a transshipment, this strictly means that a container both enters and leaves the terminal on the waterside.

Some terminals are specialized in dealing with transshipment. One of the largest terminals in the world is located in Singapore and due to its strategic location as an entry to the rest of Asia deals mostly with transshipment; in fact, it is an 80% transshipment terminal (Saanen, 2004). Not all large terminals are transshipment terminals: the port of Rotterdam is the largest port in Europe, but has a transshipment rate of only 20%-30% and is therefore considered an import-export terminal (Saanen, 2004). This is not surprising, considering the main strategic advantage of the port of Rotterdam is its good connectivity to its hinterland.

The other function of a terminal is storage. Terminals have a limited area at their disposal. They have to reserve space for all kinds of purposes: the quay will require a strip for quay cranes; behind the quay cranes will usually be an apron; there need to be racks for refrigerated containers (*reefers*). Some containers container dangerous goods (often dubbed *IMOs*) and require a separate storage area. Some containers are

⁴http://www.maerskline.com/link/?page=brochure&path=/about_us/company_info - accessed on May 7, 2010

⁵http://www.ships-info.info/mer-emma-maersk.htm - accessed on May 7, 2010

⁶http://www.embassyfreight.nl/logistiek/bedrijf/nieuws/81_emma_maersk_onbetwist_de_grootste.html - accessed on May 7, 2010

⁷http://www.nieuwsbladtransport.nl/download/14000_TEU_class_DSME_1.pdf - accessed on July 12, 2010

^{*}http://www.marinelog.com/index.php?option=com_content&view=article&id=532:2011feb0002100&catid=1: latest-news&Itemid=107 - accessed on April 19, 2011



Figure 2.2: The functions of a container terminal *Source: Saanen, 2004*



Source: Dobner et al., 2001

oversized; many terminals store break bulk cargo as well. There needs to be an office building, a maintenance facility, gate facilities. However, the biggest space is necessary for the main container yard, which can be several square kilometers for the largest terminals. However, with the large quantities of containers handled at these terminals, storage space is still at a premium. Moreover, any terminal will be more efficient with fewer containers sitting in its yard: with fewer containers, the number of unproductive reshuffling moves can be limited and each container has a higher chance of getting a good storage spot. For an export container, this means that it has a spot close to where the vessels berth. The largest terminals have a quay of several kilometers. Small to midsize terminals may still have a quay of about a thousand meters.

When an export container is brought in through the gate, it will stay at the yard until the vessel on which it has to be loaded is ready for receiving it. Depending on the terminal policy and contracts with their customers, there will be restrictions on the time in which this can happen. Typically, export containers can be brought in starting from about two weeks before a vessel is due to arrive. Depending on the flexibility of the terminal and liner, a container needs to be at the terminal one day before the scheduled or actual vessel arrival at some terminals, while it can still be delivered while a vessel is being loaded at some terminals. Customers can pick up import containers at their convenience after it has been unloaded, but at some terminals there are restrictions on how long they can stay. Transshipment containers stay in the yard until the connecting vessel is being loaded. The duration at which a container is sitting in the yard is called dwell time. One of the prime factors related to terminal efficiency is therefore the average dwell time (Saanen, 2004).

As not all container transport flows are symmetrical, not all containers being shipped are full. In fact, managing the availability of containers and the ratio of full containers in container transport flow has been a problem from the very early days of containerization (Levinson, 2006). Nowadays, container vessels may carry large number of empty containers (*MTs*) and terminals may store large numbers of them as well. As MTs have no payload, their total weight can be much lower than that of full containers. For this reason, more of them can be stored on top of others. In order to limit the space needed to store these MTs, terminals often employ separate MT yards, which can be operated by lighter equipment than full ones. As the accessibility of MTs is less critical, MT yards can usually be situated at slack space in terminals which is remote or hard to reach.

Developments in the role of the terminal in the transport chain

A development in the role of terminals in the shipping process is that of the dedicated terminal (Douma, 2008): liner shippers work closely with a terminal that is (almost) exclusively dedicated to them as its single customer. Besides seeking cooperation with their competitors on sea (Cariou, 2002), liners seek closer cooperation with landside parties (Notteboom, 2007) as well. Some liners offer carrier services, by taking over the entire transport chain and developing direct relations with the shippers (Notteboom, 2007). Single-user terminals are part of this strategy; by securing transshipment capacity, liners try to control the reliability of their transit times (Douma, 2008).

Another development is that of terminals' awareness of their role in the entire supply chain. Vernimmen et al. (2007) observe that terminals are showing increased interest in cooperating more with other actors in their supply chain. In the end, shipping service customers pick the fastest supply chain, not the fastest terminal. If going through a different port offers them more value, they will switch. Terminals therefore compete on a supply chain versus supply chain level, rather than solely on a terminal versus terminal level. As such, they share business stakes with other actors in their supply chain. Examples of this development can be found in projects where terminals cooperate more with barge operators in finding favorable berthing windows (Moonen et al., 2005; Moonen, 2009; Van Hövell tot Westerflier, 2009)

Finally, there are developments in the manner in which terminals allocate their resources to other market players. According to Rodrigue and Notteboom (2009, page 165), they are "increasingly confronting market players with operational considerations such as imposing berthing windows, dwell time charges, truck slots, all this to increase throughput, optimize terminal capacity and make the best use of available land." They call this process *terminalization* (Rodrigue and Notteboom, 2009), and also include developments in inland container terminal usage in this concept: they argue that inland terminals are more and more often used as extended deep see port storage facilities or gates (Rodrigue and Notteboom, 2009). An example of this can be found in the Extended Gate concept introduced at ECT Rotterdam (Veenstra and Ham, 2009). Dwell time can also be restricted in other ways, for example by limiting the number of days before a port call when a container can be dropped off. A scheme like this has been implemented for example at the ECT Delta terminal in Rotterdam, in order to increase productivity by decreasing the stack size.⁹

2.4 Developments in liner shipping and their effects on terminals

As discussed in sections 2.1 and 2.2, the container industry has seen some tremendous growth. Due to the economic crisis, 2008 and 2009 have been disastrous for the shipping industry. Although there has been some optimism lately, the shipping industry analysts of Drewry still advise caution, reminding that figures are still not up to the levels of 2006.¹⁰ Whether or not the crisis is over remains to be seen. However, besides mere growth, it has been the liner shippers' relentless pursuit of economies of scale that drives the increasing demands on container terminals as well.

Saanen (2008) offers the opinion that terminals have been focusing their efforts on keeping up with growth for so long, that they have neglected to keep their operational efficiencies in check. As a result, "there is waste, much waste in terminal operations". Now that levels have plummeted, it has become more important than ever for terminals to cut operational costs: not just to keep their head above water in these dire times, but also to be prepared for a renewed growth phase in the future. Similarly, Notteboom and Rodrigue argue that the transformation to a supply-chain based global economy has stretched the container concept and that "smarter management of the container system and its related networks is a prerequisite for a sustainable deployment of the container concept in global supply chains in the longer term." (Notteboom and Rodrigue, 2008, page 157)

2.4.1 Liner shipping networks as a source of terminal complexity

Some of the developments container terminals have undergone can be traced back directly to developments in the liner shipping world. In order to get a better understanding of how these developments came to be, it is necessary to take a closer look at these liner shipping services. (Notteboom, 2006) discuss the challenges of running a liner shipping service. They set off by explaining the objectives of such a service: "low operating costs, high frequencies, fast transit times, and both tight and reliable voyage schedules."(Notteboom, 2006, pp. 19-20) They argue that one of the main logistical concepts facilitated by the rise of containerization, Just-In-Time production, in turn places high demands on the time factor in liner shipping services. The focus of their effort was therefore on the time factor. They discuss how the time factor is related to the design and operation of a liner shipping network.

According to Notteboom, the service design is mainly viewed as a strategic planning problem. Taking market demand into account, service planners need to make decisions on service frequency, the type of

⁹http://www.nieuwsbladtransport.nl/nieuws/id19302-ECT_terug_naar_de_discipline.html - accessed on August 17, 2010

¹⁰http://www.joc.com/maritime/drewry-warns-against-rosy-container-forecasts - accessed on May 7, 2010

ships that run each service and the number of port calls in a loop. Services usually run on a weekly basis, but it is also possible that a service runs five times in 8 weeks for example. Notteboom (2006) argues that in their pursuit of a larger productivity, the operational patterns in the design of services and networks of services have had an equally important role as the increase in vessel sizes. Network design patterns have evolved from simple end-to-end routes to a more complex composite of routes, where the network design is defined by the pattern of an individual route and the manner in which these routes are combined. Depending on its origin and destination, a container may be shipped to its destination over a number of segments.

The developments in the way liner shippers design their network have consequences for terminals. An increase in the level of segmentation in individual container's trajectories will lead to more transshipment. As noted by Notteboom and Rodrigue (2008), when liner shipping companies are applying a bigger degree of flexibility and complexity on their service networks, the resulting cargo flows for terminals will be more dynamic as well. Terminals may find themselves a regional hub for one network and a feeder terminal for others, all dependent on the dynamic considerations that liner shipping companies are making on strategic, tactical and operational levels.

As network designs change, and liners move their business from one terminal to another which offers strategic benefits in a new network design, terminals can see much of their business leaving overnight (Rodrigue and Notteboom, 2009). This will result in a more dynamic load on terminals, with effects on long-term demand for each terminal's services, on peak load, and on service level demands. Additionally, the manner in which a terminal is used has an impact on the efficiency: applying the same approach to a transshipment and an import/export terminal can lead to very different results for example. In order to be efficient, terminals need to adapt their approach to the quality and quantity of demand. If this manner is dynamic, the approach should be as well.

2.4.2 Liner shipping operations as a source of terminal complexity

While the network design has consequences for terminals over a long term, consequences that are more short-term in nature are the result of liner shipping operations. As operations at the terminal are tightly coupled with vessel operations, their problems are coupled as well. As it is, shipping companies have big problems with keeping the integrity of their schedules. Vernimmen et al. (2007) and Lang and Veenstra (2010) report on an investigation carried out by Drewry Shipping Consultants (2006). Vernimmen et al. (2007) report that only 52% of all port calls of container ships occurred according to schedule. 21% of the calls were 1 day late, 8% 2 days, and as much as 14% were 3 or more days late. Drewry's figures for 2008 (Drewry Shipping Consultants, 2008) show a similar situation, with on-time vessel arrivals not exceeding 50%.

There are many reasons why vessels can run into delays. Vernimmen et al. (2007) list bad weather, congestion or strikes at earlier ports of call and knock-on effects from earlier delays as the reasons for delays. Notteboom (2006) gives operational issues at terminals, issues with port access and access to maritime passages and chance as reasons for delays. Some ports are accessible only in specific tidal windows; maritime passages such as the Suez canal are only accessible in daily windows as well. Missing these windows by a small account will result in much larger accumulated delays. The chance factor includes bad weather, equipment breakdowns, and unexpected waiting times at bunkering sites and ports. Notteboom (2006) refers to delays that accumulate over a vessel loop as intra-roundtrip effects. Inter-roundtrip effects are, for example, the result of a large variability in waiting times between calls of a service: 8 days, 6 days, 4 days, all for a weekly service. While a liner shipper may employ buffers in their schedule to compensate for delays, these buffers will be very costly. According to Notteboom (2006), the Swiss company MSC op-

erates as a low-cost carrier. It calculates very little buffer time, and usually responds to delays in a creative ad-hoc manner. Maersk, a major carrier from Denmark, operates with more buffer time and is therefore more costly, but as a result manages to maintain a higher level of schedule reliability.

Shipping schedule reliability and liner countermeasures

Notteboom (2006) discusses that schedule reliability is not the same as transit time reliability: the former refers to whether a vessel is on time in its ports of call, where the latter refers to whether a container is delivered on time to the client. Even when schedule reliability is low, carriers may take measures to not let their transit time reliability drop as well. As mentioned in the previous paragraph, MSC in particular is known for devising creative ad-hoc solutions. They and other carriers may decide to skip ports of call or reverse the sequence of ports of call, or deliver a container to a different port than planned earlier and ship it to its final destination through the hinterland. They may employ a different vessel to take some containers. Especially in terminals with access only in specific tidal windows, or in cases where other strict deadlines apply, vessels may exercise the "cut-and-run"-principle: they leave containers behind at the terminal that have not been loaded yet at the last minute in order to leave on time (Notteboom, 2006; Meisel and Bierwirth, 2009). Containers for which the vessel on which they are loaded are different as the one originally planned are often referred to as "rollings" (Van Putten, 2005).

When only looking at schedule reliability and the measures that can be taken to try and upkeep schedule reliability once a delay has been encountered, there are really only two things that can be done: shorten the time at sea, or shorten the time in port. The latter is possible for some ports; according to Notteboom (2006), Antwerp is often visited as a first port of call from Asian routes because it can facilitate high turnaround times when necessary. It is therefore regarded as a 'safety valve' of sorts. This doesn't apply for most terminals however, which have difficulty in coping with high performance demands. The former option, decreasing time at sea, is done by operating at higher sailing speeds. This option is becoming more and more costly however, as the price of oil is rapidly increasing and the consumption of fuel is non-linear with regards to the sailing speed. Recovering only a small amount of delay comes at a large premium in fuel consumption. Increasing bunkering prices will therefore lead to even higher pressures on terminals to facilitate fast turnaround times.

Consequences for terminals

The effects of all these ways of dealing with delays on terminals are considerable. Facilitating fast turnaround times in itself is very expensive because it requires a high peak capacity; as the peak load increases, general utilization of each piece of equipment drops (Saanen, 2004). Basically, terminals need to spend more on equipment that does less. The other responses carriers may take on delays are wrecking for terminals as well. Delays themselves that result in a container ship missing its contractually negotiated berthing window affect both berth planning and yard planning at terminals. Yard space that was expected to be vacated due to export containers being loaded may suddenly still be taken. Containers that were supposed to be on top of a stack so that they could easily be taken to be loaded on a vessel may suddenly have been topped by import containers that couldn't be fit elsewhere on the yard. This all results in many extra - and costly! - reshuffling moves.

The uncertainty in arrival times means that terminals will need to take bigger margins in their reservations of workforce and equipment, that may ultimately end up sitting and waiting for a ship that's late. They may even need to hire extra workforce to catch up on a late schedule. The measures taken by carriers to counter their delays can be even more devastating: 'creativity' in the port calling schedule leads to even higher uncertainty with respect to terminal planning, rolled containers are a serious burden on a yard.

Vernimmen et al. (2007) explain that vessel delays can lead to snowball effects for ships berthing at the same terminal, aggravating problems even more. These snowball effects apply to most processes however; problems generally lead to more problems, and send terminals racing to catch up on a failed schedule.

2.5 The terminal as a technical system: a closer look on terminal operations

The previous section gave a basic overview of the role of terminals in the shipping process. Now, the processes at the terminal and the resources used to execute these processes are discussed in more detail. The main processes are the seaside operations, the moving of containers across the yard, and the moving of containers into and from the stack. The various alternatives in equipment for handling this together make up the logistical concept. The strategy in choosing a logistical concept will be discussed as well.

2.5.1 Seaside operations

As mentioned in the previous section, containers are brought in at the waterside by vessels docking on a quay. In order to distribute ships along the quay, each vessel is assigned a specific berth where it may dock. Quay cranes then start discharging a vessel by lifting containers from the ship onto the shore. When a vessel operation is under execution, one or more QCs will be handling the sea-to-shore container moves. This number may vary depending on the size of the ships and the stowage plan. Depending on the size, there are physical limits on the number of cranes that can be allocated.

The largest ships such as the Emma Maersk are almost 400 meters long and may be served by as much as six cranes at a time. Smaller deep-see vessels are typically served with 3 cranes, smaller feeders with two cranes and river barges with a single crane; some terminals have a dedicated barge crane that is a better fit for these small vessels than the massive Post-Panamax or Super Post-Panamax cranes that are beginning to be more common at terminals. As for the stowage plan, the division of the containers to be handled in a call across the vessel's bays determines how many cranes can be allocated over time. This allocation of cranes over bays is often referred to as the crane split.

The productivity of the quay crane is often different in reality from its technical capacity. While the technical capacity of modern cranes may be as much as 50 moves per hour, the actual productivity often is in the range of 25 to 30 moves per hour. This has to do with physical circumstances, crane operator skill, the vessel stowage and the productivity of equipment that has to move containers to and from the quay cranes.

Weather influences

Weather in the form of wind, waves and currents may lead to berth inaccessibility due to unacceptable ship motion or mooring line loads, or inability to operate the quay cranes (Thoresen, 2003, page 147). In general, terminals will seize operations of wind speeds exceed a certain threshold. Thoresen (2003) puts this threshold at 20 m/s, but experience tells that these differ between terminals based on their choices and safety policy.

Excessive wind may therefore lead to a complete halt of operations; at heavy winds, entire quay cranes have been known to roll across their tracks until stopped by another crane. But even at lower wind speeds it can hinder operations. Spreaders will start swaying due to wind forces; this makes the crane operator's job much harder, and can significantly deteriorate crane productivity.

Vessel stowage

The vessel stowage is about the location of containers in the vessel (below deck or on deck), the type of containers that need to be handled (full or empty, normal, reefer or IMO cargo), and the distribution of the containers across the bays. In order to keep the quay cranes moving, resources that take containers from the yard to the quay crane need to be allocated to feed the cranes. Most terminals assign these yard resources to quay cranes in a dedicated manner, but other alternatives are available: these movers can be pooled between cranes, vessels or all operations. Typically, about three of these yard resources (trucks and cranes) will be assigned to a crane.

Vessel operations

During the seaside operation, several other processes are going on at the vessel itself. First, there is the operation of hatch covers. Hatch covers on a container ship cover bays during transit. These must be lifted and placed back during operation by the quay cranes, using up precious time for these crucial resources. Crew must be present while operating on these hatch covers.

Secondly, containers may be fastened using twist locks. However, these are often not enough to hold containers together under extreme duress. For this reason, containers may be *lashed* together. The number of lashing rods required to lash a vessel is large; there are thick handbooks and guidelines for each vessel on how to properly lash containers. As such, this is a lengthy process as well requiring several workers. In some cases, the ship's crew can handle lashing; in other cases, the terminal will have to arrange lashers for the operation. As can be seen in fig. 2.4, it is not a trivial task: several configurations are possible, depending on the size of the stack. Lashes may be crossed or parallel, fixed to the hatch covers on deck or to lashing bridges. Whether proper lashing saved the Ital Florida's other containers or improper lashing caused the accident in the first place is unknown.¹¹



(a) Lashing rods (source: A master's guide to container secur- (b) The use for lashing rods: the Ital Florida lost several coning, Murdoch and Tozer (2007)) tainers

Figure 2.4: Container Lashing

Finally, vessels may be serviced while staying in port. This includes minor repairs and fuel bunkering. Depending on how much fuel needs to be bunkered and the call size, the operation time and bunkering time may be similar. Operation time can sometimes be adjusted to bunkering time.

¹¹http://www.samudramanthan.in/IDP_problem_statement.pdf - accessed on August 18, 2010

2.5.2 Moving containers across the yard

After containers are lifted from a vessel, they are brought to the yard by movers. There are many ways in which this can be done, in terms of different kinds of equipment and different kinds of operational logics. Altogether, the way in which containers are transported over the yard is called the logistical concept.

There are a number of logistical concepts available, determining how containers are transported and lifted within the terminal. First of all, the equipment in the terminal may be handled manually or automatically, in which case we speak of an automated or robotized terminal. Secondly, a system must be chosen to determine how containers are transported within the terminal. Some kind of internal transporters are needed, which are sometimes referred to as prime movers (PMs). A number of options are available: terminal trucks (TTs) or straddle carriers (SCs) are some of the most picked alternatives for manually operated terminals, whereas Automated Guided Vehicles (AGVs) are used in automated terminals. There are a number of variations for most of these types of vehicle, each of which has its advantages and disadvantages.

Finally, there are two secondary types of container handling equipment. Empty containers may be handled by MT handlers which can typically stack containers up to 7 tiers high. When moving containers over larger distances, it may be more efficient to collect a number of these by the prime movers and place them on a multi-trailer. In Rotterdam's terminal, multi-trailers are employed for inter-terminal transport as well.

2.5.3 Yard design

Finally, a yard lifting system must be used to take containers from their carriers and place them in the yard. This design parameter is connected to the yard design. Murty et al. (2005) describe how a yard is typically laid out. A yard is usually divided into rectangular zones called storage blocks, or simply blocks (see fig. 2.5). These blocks are separated by truck lanes (Chen and Chao, 2004). A block is divided into rows (or lanes), each of which has six spaces (sometimes called bays, according to Chen and Chao (2004)). A seventh space is reserved for transporters passing; a yard crane moves over a row, lifts a container from its position, and then lifts it to the seventh lane in order to lift it on a transporter. Each row has a length; according to Murty et al. (2005), a row is typically twenty TEU long. In this manner, a matrix is formed of containers. Saanen (2004) refers to the cells in this matrix as Terminal Ground Slots (TGS), with the size of each TGS being the footprint of a twenty-foot container. On each TGS, a number of containers may be stacked on top of each other. The stacking height is determined by the type of yard crane used for that block, and is equivalent to the number of tiers in a block.

2.5.4 Yard cranes

There are a number of options available for lifting a container from its stack. On a terminal that is operated by straddle carriers, the SC can drive over a row and lift a container itself. When terminal trucks are used, a yard crane will be required to lift the container from the stack and onto the truck. The most widely used types of crane are the Rubber-Tyred Gantry Crane (RTGC, fig. 2.6), the Rail-Mounted Gantry Crane (RMGC) and the Overhead Bridge Crane (OBC). The chosen logistical concept leads to a maximum stacking density, expressed in TEU / hectare. It is important to realize that this stacking density is different for each concept: a straddle carrier has big legs; there has to be space for these legs on both sides of every container, because a straddle carrier can only drive over one row. Compared to a SC, a RTGC covers more rows, which results in a slightly higher TGS / ha. A main difference between RMGs and RTGs is that RMGs can drive whilst carrying a container; RMGs cover even more rows, but significantly higher TGS densities are reached only when RMGs are used that deliver their container at the end of a block rather than at the





(a) Bay

(b) Row



(c) Tier

(d) Pile

Figure 2.5: Subdivisions of a Container Block



Figure 2.6: A Rubber-Tyred Gantry Crane lifting a container on a terminal truck Source: Murty et al., 2005

sides, like a RTGC. Because this leads to longer movements, this results in a trade-off between the stacking density and the handling speed that is a crucial factor in determining the annual throughput of the terminal as a whole.

2.5.5 Gangs: the makeup of terminal operational workforce

Section 2.1 discussed the gangs of longshoremen that used to work on the docks in the days before containerization. Although the manual handling of cargo is absent at terminals, gangs of dockworkers still populate modern terminals. The distinctive traits and peculiarities of this workforce have all but vanished. In many countries, unions still are strong and exert influence over the organization of labor.

The makeup of these gangs can be different throughout different countries and terminals, but due to standardization and the processes that all terminals share, commonalities can be found. Farré Barberà (2009) discusses the makeup of gangs at APMT's straddle carrier terminal in Virginia. She notes that some functions are obsolete, but in place due to union agreements. A gang at APMT Virginia includes a dock foreman, a ship foreman, a checker, two crane operators, six straddle carrier drivers, a header in charge of the drivers who uses a forklift to drive baskets of twist locks under the cranes, three twist lock handlers at the vessel plus one header, and six lashers plus one header.

Out of these, the crane operators are two in number by union agreements; one is required. Only three straddle carrier drivers are required; they alternate in two-hour shifts. The drivers could also function as checkers, but are by union agreement not allowed to type numbers while working. The number of lashers is also six by union agreements, even if less are needed.

2.6 Container terminal planning

As was discussed in section 2.3, the main functions of a terminal are the transshipment and storage of containers. While both of these activities are simple enough in itself, it is the scale at which container terminals operate that necessitates planning them. Even more, it is the quest for efficiency that necessitates good planning. Basically, running a container terminal is about the allocation of resources. Moving boxes requires equipment, a starting location, a destination location, people to handle the equipment. In order to provide and allocate these resources, a planning needs to be made. In order to be efficient, there need to

be restrictions on the number of resources a terminal has at its disposal. The level of demand is different every day. Therefore, decisions need to be made constantly about the number of resources and where to allocate them.

Overview of container terminal planning decisions

Planning at terminals is usually segregated across a number of branches. Although the distinctions may be blurred in reality in some cases, usually several planning areas can be distinguished. This includes yard planning, vessel planning, berth planning, equipment planning, workforce planning, and maintenance planning. There are also dispatching decisions during operations. An overview of planning decisions is given at fig. 2.7. These decisions differ in the time granularity. Based on the granularity, they can be identified as planning, scheduling or dispatching decisions (McKay and Wiers, 2006). They also differ in the objects of the plan.

Berth planning

The area of interest in this thesis is berth planning; this choice of focus was motivated in chapter 1. As will be discussed in more detail in section 2.4, container shipping is organized in a service-oriented manner: liner shippers run a regular service around a number of ports. Usually the services sail on a weekly basis. They contract terminals in these ports to load and discharge their vessels. Because terminals have long-term contracts with their customers, they more or less know what vessels are scheduled to visit their terminal on a regular basis, for each day of the week. Based on these long term schedules, they make pro forma plans of their operations: what vessels will berth where, at what time, how many containers need to be loaded and discharged, how much people and equipment needs to be allocated to each shift?

However, the actual arrival times of vessels are highly uncertain: only half of the vessels arrive on time. This complicates matters, because it produces high peak loads in the arrival of vessels. These changes are the cause of great challenges to berth planning. Especially at large terminals, many vessels may visit the terminal at the same time. One of the main goals of a good berth plan is to let a vessel berth as near as possible to the locations of containers that will be loaded onto it, to discharge locations and to the berth of vessels that will take transshipment containers from this vessel. This may be difficult when many changes have to be made to a plan and berth resources become more scarce. Additionally, the various resources required to handle a vessel must be available at the given time and berth. Therefore, berth planning is highly interdependent with vessel planning, yard planning and equipment and workforce planning.

Managing this interdependency well may have large benefits for terminals. The berth plan stands at the root of all other plans, and when plans are aligned at an early stage this can mean savings in idle labor, a yard that is easier to manage and increased berth productivities during vessel operations. Just this last benefit is substantial: the difference between one berth and a slightly better one may average out to be one move per hour, and in some cases it may be as much as 3 or 4 moves per hour. When handling a large vessel with four gangs, this can easily save one or two hours on the operation. As running one gang may cost over $\leq 1,000$ an hour in labor, fuel and power costs, savings easily add up to about $\leq 10,000$ per vessel. When opportunities to improve on the berthing decision present themselves only a couple of times a month, still the combined savings may add up to be somewhere between $\leq 50,000$ and $\leq 250,000$ a month, depending on the size of the terminal and level at which berth decisions improve.

Plan pro Plan pro Weeks forma forma Plan rosters Plan time schedule schedule slots View yard expected fluctuation Planning Determine Update Days gate lanes allocations & Assign berth filters location Plan shift Plan shift Plan shift Plan shift Assign deployment deployment deployment deployment cranes to vessel Determine Determine Shifts deployment deployment Create per type per type Assign tracks Determine Stow plan & cranes deployment Scheduling ____ Dispatching Assign QC to hatch Create house Create QC keeping Work queues moves Hours chedule QC Schedule PM Schedule Schedule RC moves in moves in yard crane moves in time time time moves Reposition yard crane Minutes Determine Assign move Assign yard Assign move load to PM location to yard crane sequence Berth Yard crane Rail Vessel Yard Gate Labour Crane Transport Figure 2.7: Overview of container terminal planning decisions

Source: Internal presentation, TBA & Quintiq

20

Based on the granularity, the design of the pro forma schedule can be considered a planning decision while the design of actual arrival plans can be considered a scheduling decision. In practice however, both decisions are referred to as berth planning. This thesis deals with the latter and will continue to refer to it as berth planning, which is then the problem of assigning a berth location and berth time window to visiting vessels, the arrival times of which are dynamic, in such a way that contractual obligations to these vessels are fulfilled, and with the lowest possible costs down the terminal operating chain. It will be discussed in more detail in section 3.1.

Vessel planning

Although terminals have indications of call sizes beforehand, these actually differ in reality as well. During vessel planning, a crane split is determined. The stowage plan is also handled by the vessel planning. This stowage plan deals with which containers need to be moved to and from the ship, and in which order. This is usually not solely decided by the terminal; the liner needs to take several factors into account which fall outside the scope of a single terminal. The stowage plan should be optimal for all port calls. Also, it should be such that the vessels weight distribution remains fairly equal. If not, the ship will start rolling or pitching, thereby hindering operations: the angle at which a spreader is lowered into a vessel can not be controlled. It can possibly even lead to hazardous situations. This includes the creation of torsion stresses across the vessel's hull (Wilson et al., 2001).

The allocation of quay cranes to vessels upfront may be characterized as a scheduling decision, while the actual handling of the vessel during operation is a dispatching decision. At many terminals, the allocation of quay cranes is included in the berth plan.

Yard planning and yard strategy

When a logistical concept is chosen, the yard equipment is fixed. Depending on the actual terminal throughput and dwell time, there will be a certain number of containers sitting in the yard. Depending on how many containers there are and the stacking height, there will be a number of free positions for new containers. When an operation is planned, attention can be given with respect to the yard to the location of transshipment and export containers that will need to be loaded onto the vessel, and to the free locations that can be assigned to import and transshipment containers being discharged from the vessel. Based on these locations, the decision of berthing location will lead to driving distances for the vessel being planned, for connecting transshipment vessels, and to the gate modality for import containers. The goal of yard planning is to keep these driving distances to a minimum, while ensuring efficiency in yard operations and space usage.

Basically, there are three strategies for laying out the yard being used to reach this goal: a pre-assigned yard, where the container locations for each call are fixed beforehand in one big area; a dump-and-sort strategy, where containers are dumped upon arrival in the terminal and sorted later; and finally, a dynamic strategy that determines a location for each container upon arrival. There is a trade off here: the dynamic strategy is harder to manage, while the more static strategy places more constraints on operations.

In general, a yard will have separate areas for import and export containers. It is not necessarily the case that all berths are equally close to the area where import containers are stacked. Furthermore, not all discharged containers are import containers: depending on the terminal, some containers may be transshipped to another vessel later. These containers will have to go into the export stack after discharging. The location of export containers depends on the yard strategy: when a pre-assigned or dump-and-sort strategy is used they will generally be close to each other and there will be large differences in the suitability of each berth for a specific vessel. When a more dynamic strategy is used, the overall driving distances will in general be larger, but there might be less congestion because the work is spread out over the yard, and it gives the berth planner a greater flexibility in assigning a berth to a vessel.

Especially in times where terminal operations have suffered from congestion for some amount of time, the yard layout may not correspond nicely to the strategy. The time required to keep the yard organized may not always be available, and there may not be time for housekeeping the yard in between operations. It is not exceptional that when large vessels visit a terminal, 15% of all export containers must be loaded onto the ship, and 15% of the yard capacity may be loaded with new import or transshipment containers. This results in a yard change of 30%. More extreme cases are not uncommon either. If just a few of these operations take place after another, it may not be feasible to stick to the strategy and pick suitable locations for each container. When the next vessel visits the port, it will result in even more deviations from the strategy. It also means that the driving distances expected by the berth planner based on the strategy may not match with the actual distances, because the actual situation on the yard is radically different from the strategy used to make the planning.

Labor planning

Section 2.5 discussed the makeup of terminal gangs. As discussed there, a number of functions exist in a gang. There is still a special spirit inherited from the days of the longshoremen, and unions still have a strong influence. Next to this, many countries now have regulation in place for the safety and hours in industrial functions. Together with company policy, for example to reach a higher level of job satisfaction by rotating people throughout different functions¹², these place restrictions on gang planning.

In the days of the longshoremen, the foremen ruled the dock: based on the work available, longshoremen needed to fight for work in a corrupted system (Levinson, 2006). Although these days are long gone, variability in work still leads to a complex workforce scheduling problem. Work at terminals is divided in shifts. Typically, there are three eight-hour shifts each day: a morning shift, an evening shift and a night shift. The goal of workforce planning is to provide enough people to handle all the work scheduled for a shift while accounting for all restrictions, and doing so in the most efficient manner. When gangs are booked for which no work can be provided, they still have to be paid and money is wasted. Slack in workforce capacity should therefore be minimized.

The level of the challenge this poses to a planner is dependent on the variability in terminal demand, both on the long term and short term. On the long term, a varying demand will require different number of people throughout the weeks. This means that if a terminal works with a fixed set of employees, they need a different number each week. To meet the peak demand, they will therefore need to hire people for which there is no work in other periods. Laying people off in less busy periods can be problematic or expensive. Alternatively, some terminals choose to work with temporary external staff. This may influence worker skill and predictability of workforce capacity. External staff also can be more expensive than internal staff.

On the short term, the challenge is mostly dependent on the gap between actual terminal productivity and terminal capacity: in a period when the terminal is working at capacity, it will be safe to book the number of gangs that match this capacity level. If within a week the variability in demand is small, the shifts can be divided over the week in such a way that all workers work their agreed number of shifts, while the terminal meets capacity demands for each shift. However, if demand is concentrated in some part of the week, there might not be enough workers to fulfill all positions.

¹²http://www.ortec.com/~/media//Files/Cases/English/List/A0493_APM_terminals_ORTEC_Harmony_ Workforce_Scheduling_Trade_Transport_and_Logistics_ORTEC_EN.ashx - accessed on August 19, 2010

2.7 The terminal: operational issues

The previous sections discussed the functions of container terminals, its operations and terminal planning. These are well established in literature. What has received less attention are the issues at terminals that make terminal operations not run as smooth as one would hope. Of course, every terminal is different and has its own problems. People who are experienced in this industry can probably fill an entire book with anecdotes on what can go wrong at a terminal. The goal of this section is to provide a short introduction to issues that have to do with terminal operations. While section 2.7.2 provides a very short introduction to the social complexities at terminals, issues related to terminal planning and organization will be discussed in chapter 3.

2.7.1 Uncontrollable environment: hazards and accidents

A terminal does not operate in a controllable environment. First of all, everything happens outdoors. Operations are subject to weather conditions: storm may blow against quay cranes, making them roll across their tracks. Snow may cover the terminal, blinding optical sensors or disabling movers. Mist produces visibility risks. Rain makes gangs unhappy, while lightning makes them stay inside. Frost may hinder equipment, and black ice makes a terminal yard a place where you do not want to slip with a sixty-ton container. Predicting and responding to these conditions is not always possible.

A terminal has resources like quay infrastructure and yard pavement, cranes and movers that are subject to intense use and outside weather 24/7. They therefore require maintenance and repairs. While maintenance leads to further constraints in planning, unexpected breakdowns contribute significantly to the unpredictability at many terminals. These issues are sometimes exacerbated by poor communication between maintenance or engineering departments and operations, and sometimes by poor inventory management when it comes to spare parts.

Furthermore, the millions of containers being shipped annually are not just filled with bananas. Hazardous materials are shipped; based on the quantities being shipped and the high degree of coupling between these shipments, regulations and operations, accidents are bound to happen (Perrow, 1984).

Good safety policies are paramount, but continues to be a point of struggle between the terminal and unions for example: When a quay crane boom breaks, there will be an outcry over maintenance and safety¹³, but when a worker ignores safety regulations, workers will be on the barricades in order to prevent his being fired.¹⁴ In some areas, working strikes are a frequent threat to terminal operations.

2.7.2 Operators: the human factor

Another important factor leading to unpredictability in terminals operations is that of the human factor: the yard is staffed by operators who may not always act as expected or required of them.

First of all, there are differences in skill and experience. Some crane operators will be able to lift a container over a stack of other containers in a nice arc, while less skilled operators use more edgy trajectories that require more time. Skilled drivers cut corners and drive faster than less skilled ones, sometimes exceeding safety limits on speeds.

Secondly, in other cases, the workers at some terminals may just be indifferent or careless about their jobs. They may misplace containers on the yard, causing them to be lost. They may fail to report incon-

¹³http://www.thisishampshire.net/news/4491208.Questions_asked_over_port_crane_collapse/ - accessed on August 23, 2010

¹⁴http://www.radio-rijnmond.nl/Homepage/Nieuws?view=%2FNews%2FDefault%2F2010%2Fmei%2FWilde+staking+ bij+APM+Terminals+op+Maasvlakte - accessed on August 23, 2010

sistencies between their orders and the actual yard, actually causing more of these inconsistencies. They may be careless when dropping a container by misaligning it, causing more operation time. When this is discovered, the container needs to be searched for across the yard. While in most terminals, the TOS provides an accurate picture of the yard, in some cases this picture is completely warped. But even in well ran terminals containers do get lost, taking up valuable time during operations.

Finally, they may be slower than possible out of sheer malice, or because of conflicting interests. Some drivers go for rides across the terminal when they do not feel like handling a job, or smoke a cigarette instead of requesting their next job assignment. In some cases, they even sabotage their equipment, so they can get a break while it is being repaired. When innovations are introduced, their performance measures may be lower than possible because the yard staff resist change and sabotage performance. Again, not much has changed since the days of the longshoremen: back then, dock work was a family-related affair. This is often still the case. When innovations in yard handling for example are introduced, operators know that jobs might be on the line. Because the best drivers who have nothing to fear themselves can still worry about their relatives, the performance of all drivers may go down out of solidarity.

Most terminals run under shift-based workforce schedules. As explained in section 2.6, there usually are three shifts of eight hours each day. When there is a mid-shift break, this means that each four hours the terminal operations undergo shift effects. These effects include operations halting for a period of time; this may be the break time, or the time it takes to transfer to the next shift. Additionally, performance speed may be lower right before a break or shift end. Based on TBA experience, insight into these effects can be low even in well-run terminals. For example, there may be large differences between how long operations cease during shift breaks in reality and in expectations.

Finally, the predominant culture in many ports across the world may place all kinds of restrictions on operations. Especially in places where unions are strong, there may be constraints on how workers may be allocated to operations, how long they may work and with how many, whether they may be moved to other vessels, or regulations on how they are paid and how and when schedules must be made. These issues do not come solely from terminal workers: tugboating services and port authorities may place similar restrictions on operations.

2.8 The terminal as a social system

In addition to the operational issues discussed above, terminals also have to deal with many social complexities. These complexities are present on an inter-organizational as well as an intra-organizational level. Many stakeholders need to interact with the terminal; for example, APM Terminals defines its stakeholders as displayed in fig. 2.8.

During terminal design this already manifests itself in the demands laid down by port authorities or governments. They often require as much throughput in their ports as possible, and may for example impose demands on storage densities. At the same time, they may pose very strict conditions on environmental efficiency and safety, or on labor conditions. Customs may seriously affect the operational procedures and required work at terminals.

As discussed in section 2.6, terminals are often organized into branches. It may have a separate marine department, yard department, engineering department, operations department, or commercial department. These may all have their own - conflicting! - interests. Furthermore, the operational management and ownership of the terminal does not necessarily have to be the same party. This will quickly manifest itself, especially when taking relation with terminal customers into account. Especially when a terminal is under pressure from the terminal owners, the commercial department will often want to make as favorable agreements with the lines as possible and may make promises in terms of productivity or volume that



Figure 2.8: Overview of terminal stakeholders Source: APM Terminals, in Farré Barberà (2009)

are not properly balanced with the effort required from other departments. Yard management may have conflicting interests with marine departments, for example when catering for the needs trucks rather then optimizing for waterside productivity.

On the inter-organizational level, terminals will have to deal with other parties. The most important are the customers, but terminal is often dependent on other parties as well. In many cases the port authority may run the piloting services to tug vessels into the port. External lashers may be required, or in some cases even external labor. Some countries have very strong unions for longshoremen, and this may affect terminal operations and management on a fundamental level.

Many of the social issues also have an effect on berth planning. These will be discussed in more detail in chapter 3.

2.9 The terminal: round-up

The past chapter introduced the concept of the container terminal. It discussed its history, its function, its role in the shipping process, its customers, its operations, its planning issues, and it complexities on an operational and social level. The goal of the chapter was to bring the reader up to speed with the topic under review in this thesis. Using the concepts described here as basic stepping stones, the next chapter will focus more on the chosen problem within the field: that of container terminal berth planning.
In theory, there is no difference between theory and practice. But in practice, there is.

Chapter 3

Attribution in theory: JAN L. A. VAN DE SNEPSCHEUT Attribution in practice: YOGI BERRA

Problem Analysis: The gap between berth planning in theory and practice

Container terminals and their operations have been widely discussed in literature. Much of the discussion focuses either on Operations Research and simulation approaches to container terminal operations, or on the broader organizational picture of the container shipping industry in general. However, the actual nature of terminal operations in practice has not received the same level of attention. The experiences at TBA suggest that operations in reality are much more messy than the rather 'clean' picture often discussed in literature. In order to get a grasp on the nature of the problems and opportunities present in the container terminal industry, long and wide-ranging discussions were held with TBA staff.

Additionally, two terminals were visited as part of the research carried out for this thesis project to get a better grasp on the problem, and what should be the goal of the proposed decision support tool. This chapter offers a problem analysis of berth planning based on the literature available, the experiences from TBA staff and the experience during the terminal visits.

First, section 3.1 will discuss berth planning and its role in terminal operations. What decisions are made, what consequences do these have and what are their goals? Secondly, sections 3.2 to 3.4 will discuss how berth planning is done in practice and what issues exist. Finally, section 3.5 will wrap up the analysis and discuss what can be done to improve berth planning at terminals, and what challenges one have to face in doing so.

3.1 Operational demands: the role of berth planning in terminal operations

Section 2.6 discussed berth planning as the problem of assigning a berth location and berth time window to visiting vessels, the arrival times of which are dynamic, in such a way that contractual obligations to these vessels are fulfilled, and with the lowest possible costs down the terminal operating chain. It is based on the arrival times of vessels scheduled to visit the terminal. These times are constantly changing, and as a result a berth plan is continuously adapted: it is always a work-in-progress document. Some time before a vessel will visit a port, the agent from the liner will send an update to the terminal about its expected arrival time. This largely depends on when the vessel left the previous terminal; in general, the terminal

will have a good idea when the vessel will arrive about a day or sometimes several days before the port call. The berth planner will then assign a specific berth and berthing time window to this vessel.

An example of a berth plan is shown in fig. 3.1. It is visualized in a system called Navis SPARCS, which is a Terminal Operating System (TOS). The TOS controls most operations on terminals. SPARCS is the most widely used TOS worldwide. However, many terminals feel that SPARCS does not provide a lot of added value for berth planning; most terminals make their berth plans on a whiteboard or in an Excel spreadsheet.



Figure 3.1: An example of a berth plan in Navis SPARCS

The berth planner sees a vessel name and code in each block. The width of each block relates to the length of the vessel, or more specifically the length of the berth reserved. The height of each block relates to the time that is reserved to handle the vessel. The colors show the service that the vessel is a part of.

We can see that in this plan, there are two yellow blocks only two days apart: the first vessel was perhaps delayed for 5 days, or it might happen to be a service that is serviced more often than once a week. The small brown blocks are for barges: in many terminals, they use the same quay and quay facilities as deepsea vessels. The berth planner usually gives priority to larger vessels and tries to put barges somewhere in between, because larger vessels are more important and because terminals have no contractual obligations to barges.

Figure 3.2 shows a more complicated berth plan; it is taken from a TBA simulation for an existing container terminal. Horizontal lines denote reserved berth space, the blocks underneath these lines denote the number of quay cranes allocated for the call, their height representing the allotted time. The labels for

each ship are the ship type (Barge or TEU capacity) and the call size. The size of this plan highlights the complexity of the task: with as many as seven deep-sea vessels being handled concurrently, and in some cases only very small slack times existing between vessels visiting a berth, the design space for a berth plan can be large and complex.



Figure 3.2: An example of a larger berth plan in TBA Trafalquar

A ship's time in port (also called port stay or turnaround time, fig. 3.3) however is not solely determined by the time of its operations; it has to be tugged into the port and it has to be berthed. For both processes, a waiting time may apply. Tugging a vessel into the terminal may also take a lot of time. For example, in order to reach one of the terminals in Antwerp, the biggest vessels can only enter the Scheldt in specific tidal windows. A vessel may therefore have to wait until the tide is right, and then complete the tugging journey. Midway, it has to pass a lock which often produces delays. Altogether, the process may take as much as eight hours. Additionally, a vessel may have to wait additional time at the quay before it is serviced. This complicates the estimation of time at which operations may start even further.

The berth planning problem has a many facets. In order to explain the challenge better, three analyses of berth planning will be discussed in the next couple of sections. The first analysis will focus on the consequences of berth planning down the chain. The second analysis will focus on the information relevant when making a berth plan. The third analysis will focus on the actual choice problems that may be encountered when making a berth plan.



Figure 3.3: A breakdown of the vessel turnaround time, or port stay Source: Internal presentation, TBA

3.1.1 Consequences of the berth plan down the operational chain

When a vessel visits a terminal, a number of processes are set in motion based on the berth plan. The map made to analyze these processes is shown in fig. 3.4. It displays a map of the effect chain that relates to the berth plan. This map will then be broken down into smaller parts; the role of each part in the effects chain will then be explained.



3.1. OPERATIONAL DEMANDS: THE ROLE OF BERTH PLANNING IN TERMINAL OPERATIONS

31

An important chain is present in this map, which is highlighted in fig. 3.5. As discussed, the berth planner assigns a berth location and time based on the expected arrival time. During operations, a number of containers will have to be discharged from the vessel to the yard, and loaded from the yard into the vessel. Based on the berth location and the origin or destination for each of these containers in the yard, the distances that will have to be covered during operations can differ significantly. The bigger the distances are between containers and the vessel, the lower the productivity will be, given a fixed number of movers. Alternatively, more movers will need to be allocated to reach the same productivity.



Figure 3.5: The berth plan effects chain

These movements between yard and vessel service quay cranes. Each quay crane can either be serviced by a dedicated set of movers and yard cranes, or moves and cranes can be pooled. When the productivity of yard-vessel movement drops, the productivity for one or more quay cranes drops as well, resulting in a lower overall productivity. This determines how much time is needed to complete the entire operation. The longer the operation will last, the longer the equipment and gangs performing it will need to be paid. Operating this equipment determines the variable costs of a terminal for about 75%.

The length of the operation is also a determining factor for the costs of the port call in another way: operation delays lengthen the turnaround time (see fig. 3.6). While a terminal that performs poorly in this respect will lose customers, it will also incur penalties when it fails to fulfill the contract. While there are a great number of contracts used throughout the industry, in practice most contracts will arrange for some Service Level Agreement. These are usually split in two ways: the berth productivity guaranteed by the terminal, and the waiting time. For some vessels, the contractual relation is such that it is guaranteed a berth upon arrival. If the terminal fails to fulfill this agreement, it will usually incur a penalty. The same goes for the berth productivity: if the average productivity is below a certain threshold, it will result in penalties. The prime factor in determining the time operations will take is the call size: the bigger the call size, the longer operations will take. The larger the call size, the more a terminal can charge the customer for a port call.

In order to minimize these penalties and operating costs, one of the key challenges for the berth planner is therefore to make sure that the driving distances for the movers are as small as possible, by assigning a



Figure 3.6: The berth plan effects chain: Service Level Agreements and Penalties



Figure 3.7: The berth plan effects chain: container locations in the yard

berth close to the locations that the movers will need to go to (see fig. 3.7). This can be a complex task: it depends on all kinds of factors. Section 2.6 discussed a number of strategies that may be used to organize the yard. Based on the strategy, containers will be assigned a grounding location. When the terminal is busy and is suffering from congestion, it may become impossible to assigning grounding locations to all containers at places that match the strategy. This may increase the driving distances.



Figure 3.8: The berth plan effects chain: yard equipment

Another important consideration is whether or not there is enough equipment and manpower available to run all these operations (fig. 3.8). Based on the required berth productivity, a number of gangs will have to be hired. The corresponding amount of equipment like yard cranes and movers has to be allocated to the operation. Since the berth planner will have to decide when to let a vessel berth, it depends on the possibilities for hiring gangs and allocating equipment at that specific time whether there will be enough to do the job. In some cases, if the berth planner makes last-minute changes there may already be staff hired to do work that cannot be canceled any more. While it may be possible to keep them busy with housekeeping moves, this overcapacity for the period of time before the vessel arrival may also result in higher costs associated with that port call.

3.1.2 Choice problems in berth planning

The previous sections have focused on the consequences of a berth plan and the information used to make one. Here, the focus will be on the choice itself: how does the lack of information lead to a lack of insight into the consequences of a plan, and therefore a berth plan choice problem? The choice problems presented in this section are still simplified models of the problems faced when making an actual berth plan, but they are illustrative in describing them and can be seen as archetypes of berth planning choice problems.



Archetype A

Figure 3.9: Archetype A: Single-vessel berth location choice problem

In the first archetype (fig. 3.9), the problem is simply to decide for a single vessel which berth is preferred: A or B. A berth is a valuable resource; not all berths have the same characteristics. In most cases it will be necessary to take account of the scarcity of this resource, but even without this a berth problem can be complex. When we ask ourselves which berth is the preferred berth for this vessel, we touch on the subject of yard strategy. The question is which location results in the shortest average driving distances. In the above simplification of the problem, where it is assumed that all containers are in a single block, the choice seems rather obvious: berth A is closer to the containers and therefore the best choice. However, yard space is a scarce resource as well and the berth location will actually influence the placement of containers on the yard. This applies to export containers arriving between the time of the creation or update of the berth plan and the port call, and to the import and transshipment containers that will be discharged from the vessel. Choosing the best of either therefore also requires balancing considerations based on current layout versus opportunities for these "new" containers. Determining the expected productivity in a certain yard block is not straightforward because there are many non-linearities in the relation between layout and productivity. This relates to congestion factors and the specific configuration of containers within a stack: if any of the first bays in a non-cantilever RMG block is quite high, this means that containers will have to be lifted over these high bays all the time, resulting in a lower productivity. The same applies to the first rows in RTG stacks (counting from the driving lane). Depending on the operations in the time between berth planning and port call, yard strategy and the level at which the strategy was adhered to, containers may have been added to the block resulting in a lower productivity. Finally, other seaside or

landside operations in the same block may interfere with this one. The larger driving distances will have to be balanced against the opportunities associated with moving to another block. But even an estimation of the driving distances will be hard to make, because it involves predicting the locations at the time of operation for all containers that have to be loaded into a vessel as well as the discharge locations for import containers.

Archetype B



Figure 3.10: Archetype B: Single-vessel berth time/location choice problem

In the next problem (fig. 3.10), a trade off has to be made between the suitability of the berthing location and the waiting time. While an equal productivity in the second case may require more movers than in the first, it will allow the second vessel to be handled concurrently with the first one rather than waiting for it to finish service. Which choice is better is again not so obvious: while common sense would suggest that the vessel would be most happy with the solution in which it can leave the port sooner, in reality the contracts usually place penalties on berth productivity and waiting times. If the penalties for berth productivity are higher than those for waiting times, it may be better from a penalty point of view to keep the vessel waiting for the preferred berth to become available. However, experience at TBA and at terminals indicates that in some cases, the liner shipper will not insist on the penalty in some cases and there is some room for haggling.



Archetype C

Figure 3.11: Archetype C: Multi-vessel berth location choice problem

In the next problem (fig. 3.11), conflicting objectives for two vessels have to be evaluated. Here, the preferred berth location for both vessels is the same, but only one vessel can berth there at the same time. The problem is to choose which of the two is more important. This depends on the importance of the customer to the terminal, contract agreements and their associated penalties, and the order in which vessels arrived at the terminal. However, very often social factors play a role too. The relationship between the berth planner and the liner agent may influence the "leeway" or slack given to the terminal.

Archetype D

In this problem (fig. 3.12), the problem of uncertainty is taken into the picture. Here, there is no problem if all operations go according to schedule. That is often not the case: here, the service time of Vessel A might be longer than expected. In that case, service for Vessel B will have to wait. By moving vessel B to berth B, this can be prevented. Of course, such a move could be handled adaptively: once it becomes known that service for Vessel A is delayed, Vessel B can be moved. However, it may not be possible to allocate the extra resources associated with longer driving distances. Furthermore, if berth B is not reserved for vessel B other vessels may be planned there as well. Keeping two berths free for one vessel is quite costly if there is other traffic that would have been placed at the second berth if it was free. We can conclude that adaptive strategies have costs associated with them, and non-adaptive strategies will have to balance the risk of a delayed service versus the costs of a more unsuitable berthing location.

CHAPTER 3. PROBLEM ANALYSIS: THE GAP BETWEEN BERTH PLANNING IN THEORY AND PRACTICE



Figure 3.12: Archetype D: Multi-vessel service time risk problem



Archetype E

Figure 3.13: Archetype E: Multi-vessel service time risk network problem

Here (fig. 3.13), we again have to make a risk-based trade off between two choices. In this scenario, we consider placing a vessel to an unsuitable berth based on the risk of a delayed service of an earlier vessel, like in the previous problem. However, here we add another ship to second berth. Again, there is a risk that service for Vessel B might Delay vessel C. Here we have to make a trade off of the risk (and therefore the odds) of a delay in service of Vessel A, a risk of a similar delay for Vessel B at Berth B, and the costs of moving Vessel B to Berth B. If we upscale this problem to a full-scale berth plan, we can envision a risk network that all have to be weighed against each other. Deciding which berth plan as a whole is more robust to service time delays then becomes an important issue.

3.1.3 Sources of information relevant for berth planning

Figure 3.14 gives an overview of the information relevant for berth planning. It was compiled from several sources in literature, TBA materials, discussions with TBA staff and from information derived from terminal visits. It categorizes the information and provides an overview of the Key Performance Indicators that should drive the decision. While this overview has been found to roughly match the situation at the terminals visited, it should be noted that every terminal is different. Therefore the organizational picture may be different, information sources may be missing or not necessary or there may be a focus on different KPIs. However, it should succeed in telling the general story.



Figure 3.14: Berth plan information sources

40

3.2 Berth planning: the current process

The information sources important for berth planning were shown in fig. 3.14. Each of these information sources are provided by other actors, which is also shown in the figure. These actors may be from outside of the terminal, or within it. At most terminals, the organization is split up in a number of departments. How this is done varies, but usually there is an operations department that handles the planning and execution of all operations. This operations department may again be split up over a number of sections: yard, vessel and gate. The vessel section handles both the execution and planning of seaside operations. Usually the staff that handles berth planning falls under this department.

As berth planning is the root of all operations plans, the berth planner is often a nexus of information flows. Within the terminal, the berth planner has to align his plans with yard, engineering and labor planners. Often, the operations department holds daily meetings to discuss the upcoming days and go through the performance numbers of the day before. Outside of the terminal, the berth planner communicates with agents from the various customers, with ship captains, and often with external parties that handle tugboating and lashing services.

The kind of staff that performs planning work may vary wildly between terminals. In some cases, planning is handled by (former) dockworkers who have shown an interest in planning matters. They may take it on as a side job or transfer to a planning function full-time. In other cases, people are hired that have a character or education that makes them "puzzlers".

Information that planners get to make their plans may often be limited or fuzzy, and hard to combine or compare with other information they have; one of the strategies planners use to counter this is by relying on rules-of-thumb. For example, the productivity during an operation is dependent on a great number of factors that have a complex interaction. During planning, an estimate of this productivity is used derived from experience. However, this estimate may not use all the information that is available or that could be made available to get a better grip on the characteristics of specific operations. This is often because they and their systems can not cope with the intangibility of the information. It may be inaccurate or incomplete, and is therefore hard to use during planning. Therefore their plans may get the average right, but not the deviations in actual cases. Because planners have a hard time predicting efficiency and they like to err on the safe side, over time the margins used when allocating equipment for jobs builds up.

The environment at terminals may vary considerably. Service call patterns, yard constraints, equipment constraints, labor constraints: it all depends on the situation. These differences are rooted in general characteristics of the terminal. For example, terminals with a high transshipment factor will focus more on the driving distances between vessels than import/export terminals, who will focus more on the distance between gate and container and exit modalities. Planners are therefore likely to place the main stress at different places, depending on their specific planning environment and where they feel they can get most value for the terminal. Furthermore, as a result of the environment being dynamic, the main focus may shift over time as well. Developing insight may cause a similar shift of focus.

The availability of information is also central to what is included in the planning task. If information is not available to the planner, the issues to which it would relate are mostly left out of the planning process for the specific vessel call. For some issues, they rely on general rules of thumb without checking for differences between various vessel calls.

 $[\]Rightarrow$ Principle 6.2: Provide an architecture that facilitates different forms of the planning task

3.2.1 Planning tools in use

Berth planners often use a variety of tools to do their work. First of all, there is a system in which the plan is made. Often this is done in the type of fashion shown in section 3.1, with a Gantt-chart of sorts. Usually, the plan is kept in Excel or at a whiteboard. The TOS is used for managing terminal operations and storing information on a container level of abstraction, for both yard and vessel stowage.

If terminals have IT tools to assist in planning, they usually constructed these tools themselves or had something custom-built. Often, terminals use Excel to make these tools. Over time, they kept adding to their portfolio of tools. Very often, the systems they use have quite some downsides to them. They are stand-alone systems that are not linked to other systems that are used. As a result, planners constantly need to juggle information around, or need to work with information in their mind rather than from a screen. Secondly, the output they provide does not support insight and understanding. They produce tabulated overviews that are unintuitive and hard to manipulate. Third, they usually require a high level of manual information processing. Extracting, transforming or updating information becomes tedious as there are so many systems. Finally, these systems usually do not give any indication of the quality of the plans, not even in part or with hints. Deciding where to focus attention remains at the sole discretion of the planner.

Berth planning deals with comparing all kinds of information. Berth planners are constantly comparing and copying information from one program to another; the lack of compatibility between systems generally prevents them from linking this information. Many planners use a dual screen environment to ease their job, and to facilitate this comparison of information. The number of times that information has to be compared is large though. While all these comparisons between systems are at least inconvenient, it can be suspected to be an error-prone process as well.

3.3 Berth planning: operational aspects

Chapter 2 outlined the functions of container terminals, and explained some of the challenges of demand faced by terminal operations: more peaks, bigger volumes, and large uncertainty in vessel arrival times. This section will describe the complexity and unpredictability in the container terminal industry in more detail. The operational complexity resides in what happens at the gate, quay and yard during operations and has direct consequences for berth planning.

Figure 3.14 listed and categorized the information sources relevant for berth planning. The most important parameters in berth planning are the arrival times of vessels and the call sizes. The most important variables are the berth locations and the crane assignments, which are influenced by the yard state and the availability of labor and equipment. Each of these are dynamic and hard to predict. Finally, the berth planner has to deal with handling times which are not only hard to predict, but highly dependent on the other variables as well.

3.3.1 Vessel ETAs

As discussed in section 2.4, many vessels do not arrive on the scheduled day. This has effects on the containers stacked in the yard at each day and their dwell time, and on the number of ships that may have to be serviced concurrently. From a terminal point of view, this is not the sole meaning when speaking about arrival times being uncertain. What matters as well is that information on vessel arrivals is subject to change. In general, this uncertainty depends on the proximity of the previous port in the vessel's service loop. Still, bad weather or breakdowns or other reasons may cause a vessel's arrival time to change with relatively little warning. As a result, this uncertainty has to be factored in when making a berth plan.

Another very important point is that the planning interval for the yard is larger than the window from the point at which vessel arrivals becomes even remotely certain. Depending on the contract with the liner, the yard may start receiving export containers for a vessel more than a week before the call. As one of the main goals in berth planning is to make sure that grounding locations for containers correspond to the berth location. When multiple vessels that were scheduled to use the same berth also have an overlap in their port stay - or may even risk so - there is a berth conflict: the berth location becomes dependent on the arrival time.

Another thing that may happen when a vessel is considerably late is that a transshipment link is broken: containers scheduled to be discharged and then taken onto another vessel may be sitting in the yard because the other vessel already departed. This also works the other way around: the yard space that was supposed to be vacated will be occupied for a while longer.

Finally, tardy vessels may cause chain reactions in vessel berthing. Other vessels scheduled to use the same berth may be pushed back as well, until there is an opportune possibility for one of these vessels to berth elsewhere.

3.3.2 Call sizes

Depending on the strategy of the liner, the call sizes for a vessel may be constantly updated. Especially a liner like MSC may get creative with changing around cargo in general and empty boxes in particular. In the most extreme cases, a terminal may receive updates after the labor orders are placed, but order changes only days before the call are not uncommon. This may cause uncertainty in vessel handling times, as the number of gangs that the planner can allocate to a vessel is not always constant over time. When equipment or labor is scarce, multiple operations will have to share the available resources and other vessels' handling times may be affected as well. In turn, it creates uncertainty on the availability of berth resources. Additionally, it effects more difficulties in managing yard space and allocations.

3.3.3 Handling times

During a terminal operation, all kinds of uncertain factors and events will influence the productivity and consequently the vessel handling times. These range from crises to everyday occasions. Some of these issues were discussed in section 2.7, but many more of these issues can be found. Besides those issues, there are issues involved on the planning side as well.

First of all, the handling times depend on driving distances. As it is not always be possible to be certain about the grounding locations for export containers that still have to be brought in through the gate or about the grounding locations for discharge containers, the handling times are also subject to uncertainty.

Furthermore, there are differences between services and even vessel calls in how 'easy' a vessel call is. This depends on the stowage plan and which places in the vessel need to be handled; some places are harder to reach than others. It depends on the number of containers per bay: not having to move the cranes a lot saves time, and also enables crane and mover operators to get into a 'flow'. These issues are not easy to predict even with a finished stowage plan, but becomes even harder when the stowage plan is not available yet.

This stowage plan often does not become available until only one or two days before the call. This means that even a crane split can not be determined well up ahead. This crane split may often change during the operation as well, as some cranes may move faster than others. As cranes can not cross each other, the bays assigned to each crane may change. It is an evaluate-and-response game to current operations. At the end, some cranes may finish while others still have to work some bays. Some gangs can then go home early while others are still working.

Terminals depend on their customer to deliver correct documentation to containers. In practice, this is not always the case. For example, containers carrying dangerous goods (IMOs) are marked as such. Limits on their placement in the yard and in vessels apply. Sometimes, an IMO is failed to be flagged as such in its documentation. Obviously this leads to hazardous situations. However, this is sometimes discovered during an operation, while checking the container before loading. In such cases, the stowage plan was based upon the container not being an IMO. Discovering an IMO sometimes requires tremendous changes in the stowage plan, and may lead to entire bays that were already loaded being discharged again.

Finally, there may be large operational interactions on the yard. Congestion has a detrimental effect on the productivities of yard equipment, that may be transferred to the productivity of quay cranes. Multiple moves may need to happen in the same block: conflicts can happen between gate and seaside operations, one vessel and another vessel, or quay crane mover and another quay crane mover, or even movers working for the same crane. These conflicts are hard to predict as well.

3.3.4 Gang allocations

As was noted above, the number of gangs that can be allocated to a vessel are constrained by vessel and load characteristics. The availability of labor and resources on the terminal may limit it as well. Handling equipment is often scarce; when many just happened to break down in a short period of time, there just may not be enough. The same goes for labor. The flexibility in hiring labor differs per terminal. In all cases, hiring a worker is a long-term commitment, as training them costs money and time. Some terminals may have access to flexible sources of workers though, but this will come at a cost premium. As a result, terminals will always have to juggle with the availability of labor. In some cases when supply and demand just happen to close in on each other, the availability of labor may be hard to manage or even predict.

Additionally, with all the changes going on during operations, the required amount of labor may just change literally overnight. Because there are cutoffs to when labor orders can be placed, again there will be issues with availability of labor.

3.4 Berth planning: organizational aspects

The previous section discussed operational aspects in berth planning. However, there are organizational issues with berth planning as well. The idealized picture of berth planning would be one where berth planning is triggered by a customer sending complete and accurate information on upcoming vessel calls well ahead time, based upon which the terminal planners, who have tremendous insight into the nature of terminal planning and operations, get together and together come up with a berth plan that takes all other planning issues into account, and that does justice to the various contracts and performance agreements that were designed to make sure all parties' interests are safeguarded. This picture would be far from the truth; this section will describe why.

3.4.1 Hidden information

Information is key in logistics. In order to handle the enormous flow of cargo, insight in this flow is critical for all players. However, their willingness to share information is low. Infrastructure is not often adapted to connect systems, so automatic sharing of information is often not possible.

Information between terminals is not often exchanged. Little is known about best practices and benchmarks for terminals. Even terminals owned by large terminal groups often do not share their experiences and information. While some terminals cooperate by updating each other about vessel arrival and departure times or even by sending stowage plans, many others simply refuse to do so.

This low willingness to share information is also visible in the relations between terminals and liner shippers. Information about container exit modalities, bay plans and vessel arrival times is often unknown or not known in time by terminals. This leads to suboptimal performance during operations. Earlier sharing of even incomplete or uncertain information could make the life of a planner considerably easier, but it will take some effort from their customers. These customers have few incentives to share information early, so they hold on to it for as long as they can so they can still feel in control of any changes. The issues caused by this behavior are mostly felt at the terminal, even though it is the liner which suffers from bad terminal performance as well. This leads us to another point: contracting between terminals and liner shippers.

3.4.2 Terminal contracting: on agreements and incentives

Liner shippers contract terminals to handle vessels if they run large services through these terminals. These contracts usually determine the number of port calls and their call sizes. This holds for multi-user terminals as well as single-user terminals. Basically, it is an agreement on a liner shipper promise to generate container moves through the terminal, and the terminal's promise to timely handle these moves. While barges employ terminal resources at the quayside, they generally have no contractual relationship at all with the terminal (Moonen et al., 2005), like other inland modalities such as truck and rail.

Although it is common for liner shippers to shift business around from one terminal to another, especially in times of congestion, terminals often have a long-term relationship with their customers. This means that contracts are the result of this long relationship, and have grown over time. The shipping industry is conservative and risk-avoidant. Changing the terms in contracts is therefore a matter of evolution, not revolution. This means that contracts are not comparable for a single liner shipper or terminal, let alone between them.

In the contracts, a number of Service Level Agreements (SLAs) can be determined. Monetary penalties can then be linked to the SLAs. The most important of these SLAs relate to handling speed. The main concern for the liner shipper is the turn around time (Saanen, 2004), sometimes also referred to as port stay. Depending on the definition and the situation at the port, this can include all time starting from arriving at the tugboat position to finishing it (see fig. 3.3). However, this is usually not reflected properly in the contracts. They usually include agreements on handling speed in the form of crane or berth productivity, and they may include agreements on the waiting time before mooring. If a minimum crane productivity is contracted, this may well mean that the number of cranes working on the vessel has no consequence to the height of a penalty if the actual crane productivity is lower than minimum crane productivity, while this number is one of the most important factors in determining port stay. The height of the waiting time penalty may be dependent on the waiting time, or a fixed penalty is incurred when some time threshold is exceeded. If this threshold is set to zero, the agreement can be referred to as a guaranteed berth agreement.

Based on fig. 3.3, we can see how these penalties may offer perverse incentives to terminals with respect to liner shippers' objective of minimizing port stay. If there is no penalty on waiting time, it is much more convenient to let a ship wait for service until a peak at the terminal is gone and there is an abundance of capacity. The same applies when waiting time penalties are significantly lower than productivity penalties, when comparing them on their port stay impact. If a berthing time for a vessel is available upon arrival that is less optimal than one that will become available later, it may be cheaper for the terminal to delay vessel handling. If a guaranteed berth SLA is broken and the penalty is incurred, there is no further monetary incentive on the terminal to limit the waiting time.

While this may not often apply for vessels that call on time, different SLAs may apply when the vessel is late. As discussed earlier, in general half of the vessels arrive out of their assigned window; they are usually late and sometimes early. For vessels that are out of window, the berth guarantee may be void or the penalty may be lower or even void as well.

In practice, monetary incentives do not control everything. Ship captains that see empty berths while their vessel is waiting will not be pleased, and in turn neither will be the liner. Customer loyalty is also a factor for terminals, and in general they will try to limit costs for their customers as much as possible. On the other hand, liners may not always enforce penalties, depending on the situation. This means that there is some bargaining power left on both sides; this bargaining power may be used in some cases to make trade offs. In many other cases though, the result will be a sort of no man's land where neither party will thread. The result is that an opportunity for creating value on both sides through the contract is wasted.

When taking the discussion on information sharing into account, again we can see that visibility about the effects of a lack of alignment between terminals and liner shippers resides at the operational level and are not taken into account during contracting. Contracting is about volumes and penalties, not about facilitating a smooth operational relationship between the involved parties. When optimality across the chain requires one party to make costs in order to save costs for another party, it will not happen if the costs are substantial and not accounted for during contracting. The system as is functions even though it may not be optimal; liner shippers feel no monetary incentive to deliver better information to terminals, and terminals feel no monetary incentive to make large costs to save a vessels schedule.

3.4.3 Planning interdependency: managing complexity

Because many decisions are interrelated, striving for optimality is a team effort. However, it is not always approached in this way. As discussed in section 3.2, the terminal is usually split into several departments. It was argued before that these departments need to work together to match their plans. This means communication needs to work well. At many terminals, it does not: as in any companies, there will always be issues with communication and coordination. The severity of those issues really differs per terminal. It is really dependent on the agree to which management is involved and how well they manage to tie all the departments. It depends on company culture and the personalities of the various people in place.

When communication is bad, there are often information islands. This relates to operational issues as well as planning issues. For example, financial information is often hidden from planners; they have no idea about the penalties or income derived from operations. Information about maintenance schedules is often not connected to the equipment schedule; conflicts easily arise. Berth planning systems are not connected to yard information and discharge planners may not always know the most actual information on incoming containers.

It is hard to get a grip on such issues; when there are problems, there is no easy fix. There are factors that may influence it though. At some terminals, all these planners sit together in the same room; in others each department has its own office. Usually communication is better in the former case. The way in which decision responsibility and accountability in a personal and financial way is allocated across the organization also has an impact. If budgeting is done in such a way that each department is fending for itself, that behavior is usually what you can expect.

Simply demanding planners to communicate more is equally hard: these planners may have trouble in articulating their *tacit knowledge* (Polanyi, 1966) to others. Even when they are willing it may be hard to make sure all involved parties share the same ideas. Each look at the problem from their own expertise, and it can be hard to understand their reasoning. This not only applies to fellow planners, but equally to

management.

 \Rightarrow Principle 6.5: Enable decision support that acknowledges the existence of other interrelated planning decisions

3.4.4 Management leverage on planners

When trying to get a grip on planning problems from a management point of view, they will quickly find themselves unable to discuss these issues with their planners. It is hard to determine the intrinsic quality of a plan. The person best qualified is usually the planner, who has an information advantage over management. This is a problem management faces in all organizations where they have to deal with professionals (Bots and de Bruijn, 2002), and applies particularly to planning (Hofstede et al., 1995). At terminals, a planner will be able to raise all kinds of points as to the validity of a plan that management will have a hard time evaluating: the idiosyncrasies of aligning yard and marine problems based on the juggling of information they constantly have to go through makes it hard to evaluate decisions ex-post. Furthermore, while evaluating a plan is hard, it is even harder to evaluate the planner. MacCarthy et al. (2001) list a number of issues that may affect the planner's process and consequently, how to rate his performance. They consider it valuable to consider scheduler performance from three perspectives: how well schedulers think they perform, how well the organization thinks they perform, and how well they actually perform.

3.4.5 Lack of decision evaluation

Most terminals will have a strong focus on the evaluation of operations: what kind of productivities did they reach, what issues arose during operations? However, as discussed in chapter 2 planning decisions will have a strong influence on these factors. The extent to which planning decisions are evaluated is usually very limited. What decision was made, why were they made in that way, what alternatives were available, and given the way the situation evolved, would any of these alternatives have been a better choice? Can our planning procedures be changed in order to make better plans? These are questions usually not asked. The drive for improvement of planning procedures is therefore usually left to the gut feeling of the planner.

3.4.6 Insight into inefficiency

When thinking of how busy a terminal is, there are several ways to define efficiency. Obviously, one can look at the absolute throughput, or the throughput compared to the theoretical capacity of the terminal, or the productivity per allotted resources. If we think of the busyness of the terminal in terms of scarcity of resources, it can be argued that inefficiency is more visible in a busy terminal.

In a busy terminal, where resources are more scarce, the design space for berth planning decisions is small. This poses a greater challenge to planners. At some point, they will not be able to allocate the amount or quality of resources to each task that is required to fulfill them in a satisfactory manner. This requires more effort from planners to be as efficient as possible with their resources. In a less busy terminal, there will be less pressure on planners to allocate resources as efficiently as possible. Therefore, busy terminals will more quickly develop an insight into the efficiency of a plan.

This is especially true when examining this efficiency in terms of the entire supply chain. Insufficient allocation of resources will also be felt by other actors in the chain: vessels seeing their ship being handled slower or waiting for berth space, or trucks standing in line at the gate. Insufficient resources will lead to prioritization between terminal users.

Furthermore, inefficiency is also more visible in a well run terminal if this means that the terminal gathers more information and statistics that is relevant to planning tasks, because there is more transparency into the effects of decisions. A terminal that has a lot of information on the consequences of decisions will be able to evaluate these decisions better.

This means that two perverse effects are in place: inefficiency may be more prevalent in terminals that are not so busy, but at the same time it will be less visible. Furthermore, it will be less visible in a terminal that is not well run.

3.5 Berth planning: opportunities and challenges

This chapter discussed an analysis of berth planning and the issues around it. Based on this problem analysis, we can identify several opportunities for and challenges in improving container terminal berth planning. This list can then guide the analysis of available and potential berth planning support tools.

Bert planning opportunities

The most important points where improvements can be made are those that directly relate to the plans that are made:

- Effect a shift to more dynamic planning
 - In order to get the most value out of berth planning decisions, it will be necessary to start considering the plan at an early stage. Waiting until all information is in, or until the vessel is almost due to arrive means that opportunities for a better plan may have already passed. This does not mean that no adjustments should be made: as more information becomes available the plan can still be changed to reflect this newest information. When these changes can be anticipated, so can the appropriate responses to the plan. This requires thinking in terms of consequences of decisions, risks and opportunities, scenarios and contingencies.

• Improve the alignment of various plans, when possible at an early stage

The berth plan is interdependent with a number of other plans. Therefore, a good alignment between them is required. This includes maintenance plans, labor plans and equipment plans, but at many terminals the most important is probably the alignment between berth and yard. When this alignment is improved, vessel handling times and container rehandling may be reduced. As a result, substantial savings can be made in labor and energy costs and service to the customer will be improved.

To help achieve these points, the handling of information during planning can be improved on three key points:

• Improve information support: link available information

Information is now often scattered throughout all kinds of systems, mail folders, Excel sheets or even only present in the planners' minds. Constantly reading and copying this information is not just time-consuming, it is also error-prone. Furthermore, working with all this information then imposes a bigger mental workload that may inhibit understanding and insight.

• Improve information support: get more information Much relevant information is still missing in the planning process, or only gets taken into account at a late stage. Data on the current state of the yard is often unavailable to the planner. Information on financial aspects is in many cases completely absent. When it comes to customer information, the problems are that information on call sizes or information related to crane splits or transshipment moves is usually sent at a late stage. Having information available earlier, even if it is uncertain or incomplete, may improve the possibilities for making a better plan at an early stage.

• Improve information support: be able to work with early and incomplete information

Especially at early stages, much of the information that is available now or that could be made available is uncertain, incomplete or ambiguous. In many cases, the information is then not used to its full potential. When planners are equipped with better ways of dealing with this information, they will be able to make better plans. Additionally, getting more information is dependent on the ability to handle it.

Finally, there are some more organizational points which can be improved:

• Improve decision making on the long term

Planning is something that is hard to explain to others: it often deals with intricate knowledge on all kinds of details. The person doing it has often had the position for a long time. As a result, the planning usually left to the planners and decision making is not evaluated. Changing conditions are not anticipated: a sit and wait-approach is usually taken. Improvements on the planning strategies therefore depend on the planner. Improving these planning strategies can therefore be done by facilitating evaluation and training by others, or by facilitating the planner's learning and the development of insight.

• Improve communication

Communication is an issue at many workplaces, and this also applies to terminals. Aside from general communication issues, for planning it is often hard to communicate to others about plans. There are many details, it's hard for someone else to understand the planners' mental picture of the situation.

• *Improve contracts, so that their incentives are aligned with value for both parties* The contracts in place between terminals and liners are high-level and are often a bad match with the value that the contracts are supposed to safeguard on both sides. When the right incentives are in place, plans may be made that offer better value on both sides.

Berth planning challenges

While there are opportunities for improving berth planning, several challenges can be identified as well:

• Difficult to effect change in organizations

For many of the suggested improvements, organizational change is required. Effecting this change has difficulties of its own. Getting planners to change their routine, getting them to cooperate more with other planners, getting liners to share more information: these changes can not be expected to occur overnight.

- *Difficult to plan under uncertainty* Many of the suggested improvements focused on getting a better grip on the uncertainty present at terminals. However, even with improved planning the uncertainty will still be present, and will remain to be a challenge in container terminal planning.
- Data on terminal operations is often unavailable or unusable To make any predictions on how a terminal operates, input data is required. These predictions can

deal with handling times as influenced by driving distances and congestion, or yard development over time for example. As mathematical algorithms are usually not employed at terminals currently, detailed and accurate data is not required now and therefore not gathered. Gathering this data may take time. Furthermore, even when the data is available, there may be difficulties in applying it: situational factors have to be mapped to system output, and this may produce its own difficulties. Finally, some data may be available in another system that it is hard to interconnect to, or may even produce difficulties in extracting the data.

• Difficult to evaluate the quality of a berth plan

The quality of a berth plan may be hard to evaluate. Planners will be able to give all kinds of explanations and justifications for a plan being made in a certain way; from the outside, it can be hard to evaluate their merits. This means that in some cases it may be hard to establish a sense of urgency: the plans are fine the way they are now, so why should we improve. When the plans are fine indeed, this is ok. However, the planner himself may miss certain opportunities and there is no easy way to find out. Additionally, it makes the effect of changes in the plan hard to measure. Strategic changes may lead to improvements over time, but the effect may be attributed to other changes in the environment.

3.6 Problem analysis: round-up

This chapter offered a detailed problem analysis. It offered a listing of opportunities and challenges in berth planning. The next chapter will discuss what contributions have been made from the scientific community so far to improve berth planning, and match it with this analysis. Then, again based on this analysis, a new approach will be discussed.

Chapter 4 Berth Planning: Decision support

The previous chapter gave a detailed analysis of berth planning at container terminals. This chapter will shift the focus, and discuss what kind of solutions could be thought of that can improve berth planning. First, section 4.1 will discuss what contributions have been made in scientific literature so far. Section 4.2 will discuss how these contributions match the problem analysis discussed previously. Section 4.3 will discuss what other scientific literature exists that does not deal with container terminals as a problem domain, but does apply to the planning problems discussed in the problem analysis. Section 4.5 will discuss what solution is proposed here to improve berth planning in the field.

4.1 Berth planning in theory: the state of the art in berth planning OR research

There is a lot of literature on container terminal planning. All the literature found during the course of this thesis project is rooted in an Operations Research (OR) approach; for an overview, see Steenken, Voß, and Stahlbock (2004) and Stahlbock and Voß (2008). The second of these literature overviews spans half a decade and lists some 250 articles, the majority of which are operations research studies on container terminals. The earlier overview lists over 200 articles as well, which were published up until 2004.

In OR studies, real life problems are analyzed and then formalized in such a way that it produces a model that can be solved. According to a textbook discussion of Operations Research (Hillier and Lieberman, 1990, page 2), this formalization step consists of the construction of "a scientific (typically mathematical) model that attempts to abstract the essence of the real problem. It is then hypothesized that this model is a sufficiently precise representation of the essential features of the situation that the conclusions (solutions) obtained from the model are also valid for the real problem."

According to Stahlbock and Voß (2008), articles on container terminal systems deal with handling equipment, human resources, and finally assisting systems and models dealing with terminal systems as a whole. Optimization methods are applied to the ship planning process, focusing on berth allocation, stowage planning and crane split; to storage and stacking logistics; and finally to transport optimization focusing on quayside, landside and crane transport optimization. Integrative approaches consist of analytical approaches, simulation approaches and multi-agent approaches.

Berth planning in Operations Research

When it comes to berth planning, Stahlbock and Voß (2008) list several approaches. Some formulate a berth allocation problem as a "rectangle packing problem with release time constraints" (Dai et al., 2008, page 1) solved using a search algorithm. Others represent it as a generalized quadratic assignment problem with side constraints. Some may approach the problem using tabu search algorithms, others employ mixed integer programming models solved using simulated annealing.

The discussion of berth planning in Stahlbock and Voß (2008) deals with both pro forma berth planning and berth scheduling at operation-time. These are two different problems; for example, Cordeau et al. (2007) deal with the former as the Service Allocation Problem and with the latter (Cordeau et al., 2005) as the Berth Allocation Problem. Obviously the two are very much related, as the pro forma will determine the grounding locations for containers belonging to a service. Moorthy and Teo (2006) discuss how the potential for changes made in the berth plan at operation-time is limited by the choices made during pro forma design. They argue that an 'optimal' solution that does not take operational dynamics into account may be less robust to changes than a less optimal solution that employs more slack between vessels, but as a result may lead to larger driving distances under default circumstances. Their case study examined two pro forma alternatives, and they concluded that the more robust of the two would be most cost efficient. Because their model of reality is very much simplified, they argue that it provides promising results that deserves more attention.

Such attention for robustness and operational deviations is often not found in berth planning studies. Bierwirth and Meisel (2010) present a survey of berth allocation and quay crane scheduling problems. There are several ways in which berth allocation problems are studied, including spatial attributes (discrete, continuous or hybrid berths, draft constraints), temporal attributes (berthing time constrictions), handling time attributes (fixed, depending on position, depending on number of QCs, depending on a QC operation schedule) and performance measures. Especially in most continuous berth studies, the location of the vessel is not taken into account in the handling time. A notable exception is a study by Imai et al. (2005), that approaches the problem by first solving a discrete berth problem and then modifying it to optimize for a continuous quay. Many studies assume a static approach and do not impose any restrictions on the arrival times of vessels; the algorithm is free to determine a berthing time for vessels.

Bierwirth and Meisel (2010) give special attention to the integration of the berth allocation problem and the quay scheduling problem. Figure 4.1 shows their approach. They identify a berth allocation problem, a quay crane allocation problem, and a quay crane scheduling problem. They argue that solving this in a sequential way will lead to bad plans, as a quay crane schedule may not be feasible if the berth plan is too tight and may result in large inefficiencies if there is too much slack. According to Bierwirth and Meisel (2010), finding an optimal solution for these 3 problems by combining them in a monolithical fashion is computationally infeasible. Therefore, they highlight how many studies focused on providing an integrated approach by analyzing potential quay crane schedules first and then finding a suitable berth plan.

4.2 Consider a spherical terminal: the gap between theory and practice

As discussed in section 4.1, there has been a lot of research on container terminal planning in general and berth planning in particular. While this provides for a formidable body of research, the literature fails to meet the challenge offered by the actual situation in many respects.

The problem here is that the construct chosen may not always match the real problem to a sufficient



Figure 4.1: Sequential planning of seaside operations Source: Bierwirth and Meisel (2010)

degree. In appendix A, it will be argued that there is a trade off between computational feasibility and the match of the model specification to the problem. In section 4.3, the match of OR techniques to planning problems in general will be discussed in more detail. Here, a short overview of the mismatch between OR literature on container terminal planning and the actual problems will be given. In the parlance of the citation given above, several features of the situation at container terminals are missing in literature, so that the conclusions obtained from their models are not valid for the real life problem. The most important of these features that are not taken into account in OR container terminal planning research are that:

• Sub-problems are optimized in isolation

As discussed above, there are a great number of planning decisions which are interdependent. OR frequently presents algorithms for problems like berth planning isolated from other decisions at the terminal. A choice for the berthing location of a vessel may effect housekeeping moves from the yard planner, or influence the grounding locations for export containers for that vessel. In turn, the level at which these yard planning decisions are feasible will in turn affect the performance associated with the berth planning decision. Berth planning, yard planning or operation planning algorithms presented in OR (Dai et al., 2008; Wong and Kozan, 2006; Lee and Hsu, 2007; Lee and Chao, 2009) do not take this into account. Recent literature is moving towards multi-objective (for an overview, see Meisel (2009) or Bierwirth and Meisel (2010)) or even a multi-stage optimization of decision making (Hendriks, 2009). This shows that an integrated approach is possible, even from an OR perspective. However, even in these more integrative approaches, many factors important for berth planning are still missing.

• Perfect and available information

In OR research, after a problem has been molded into a form that can be solved by the OR technique, it will list a set of model parameters and variables. If the value of these variables can not be specified at the time of running the algorithm, no solution can be found. As was argued in chapter 3, the information infrastructure at most terminals is such that any algorithm that is sufficiently complex can not be fed the data it requires.

• Inability to handle uncertain or incomplete information

Similarly, when at the time of running the algorithm, not all parameters are known in a complete and certain way, the results offered by such algorithms will differ from reality. For example, when an algorithm is to evaluate the average driving distance for an operation, how will it handle locations of containers not present in the yard yet? How will it handle uncertain arrival times of future vessels? Berth planning literature ignoring these uncertain factors does not sufficiently match the real life problem. While stochastic techniques are available, they have been given little attention in berth planning research. Furthermore, much of the uncertainty present at container terminals can not be readily formalized in a stochastic way.

It can be concluded from this that when matching these observations to the list of opportunities and challenges in berth planning discussed in section 3.5, there will be issues with an OR approach. Syncing up a yard and berth plan for several days ahead will run into problems when all kinds of information is still missing. Much of the information derived from communication inside the terminal is hard to factor into an algorithm. Finally, the long-term improvement of planning requires changed planning strategies throughout the terminal. Automated planning means that when an opportunity for a better strategy requires a change outside the problem space of the algorithm, it will be missed. Because the planner is no longer actively involved in planning, the necessary insight will not be developed. As it is, planning is still too much reliant on human communication and insight to be able to automate it.

4.3 An empirical view: planning as a complex socio-technical system

Literature on planning covers a wide variety of activities, ranging from social planning to human everyday decision making. Of these varieties, the research focus matching berth planning activities best is that of production control. Depending on the granularity, scope and authority of the planning activity, production control is usually covered with planning, scheduling and dispatching (McKay and Wiers, 2006). McKay and Wiers argue that in production control, these terms all cover decision tasks dealing with task sequencing, allocation of resources to tasks and orchestrating these resources. When discussing scheduling, sequencing can be further categorized into deciding on the starting and finishing times of tasks and their sequence (Verbraeck, 1991). This view on scheduling matches that of berth planning, where the task is to assign starting and ending times of operations and deciding on the berth position of a vessel and thereby which part of the quay it will consume as a resource.

Planning and scheduling literature is then broken down into many categories even further. These categorizations can be made based on functional differences; for example, Hofstede et al. (1995) distinguish between production planning, stock control, transport planning, workforce planning and several other types. When categorizing scheduling in a more formal way, other distinctions can be made. According to Verbraeck (1991), literature mostly focused on job shop and flow shop scheduling, but other types such as project scheduling and timetabling are listed as well. While berth planning can be said to share characteristics with some of these types, its exact fit is unimportant here. On a more general level, some points can be made on how scientific literature has dealt with planning over time.

Scheduling research emerged when manufacturing factories grew in size and complexity, and the management of these factories became more important (Herrmann, 2006). Cost started to become a prime factor, and the efficiency-oriented thinking of scientific management or Taylorism¹ started to take over from the foremen who used to rule the shops (Herrmann, 2006). Henry Gantt became uniquely identified with scheduling control with his invention of the Gantt-chart (Herrmann, 2006), which proved to be an

¹For an explanation of Scientific Management and Taylorism, see http://en.wikipedia.org/wiki/Scientific_ management - accessed on August 2, 2010

extremely robust invention: it is still used in most scheduling support systems today (Wiers, 1997), including at many terminals where a Gantt-chart of sorts is used for berth planning. Later research described planning boards as scheduling tools, but with the rise of computer support, soon scheduling control became dominated by the field of Operations Research. According to Wiers (1997), an immense quantity of scheduling research was published in the operations research field.

Container terminal planning research is then no exception. As discussed in section 4.1, there is an extremely large number of OR-oriented papers on all terminal planning functions: stacking algorithms, berth planning, crane planning, stowage planning, and so on. For an overview of this literature, see for example Stahlbock and Voß (2008); their article lists some 250 articles on container terminal OR research published mostly in a time period of about half a decade. However, the role of all this research in actual container terminals seems to be rather low; the algorithms are not used in terminal practice, and as discussed earlier, berth planning is still mostly done on a whiteboard or in an Excel sheet. This too is an observation that applies to planning theory and practice in general. According to Wiers (1997), the impact of academia on industrial planning is small.

The impact of commercial scheduling support systems is low as well: "In spite of the fact that during this last decade many companies have made large investments in the development as well as in the implementation of scheduling systems, not that many systems appear to be used on a regular basis. Systems, after being implemented, often remain in use for only a limited amount of time; after a while they often are, for one reason or another, ignored altogether." (Pinedo, 1992, page 2151). McKay et al. (1988) and Mac-Carthy et al. (2001) identified the same lack of impact of academia and support systems on actual planning. McKay et al. (1988) criticized the gap between scheduling theory and practice: "The problem definition (for scheduling) is so far removed from job shop reality that perhaps a different name for the research should be considered." In some way, their suggestion may have been realized: the Wikipedia entrance for Job Shop Scheduling identifies it as a problem in Computer Science rather than one in real life.²

Characteristics of planning: the gap between theory and practice

This disparity between planning theory and practice has been noted; several gaps between planning theory and practice can be identified (Wiers, 1997). For example, Pinedo (1995) and Verbraeck (1991) list a great number of differences between job-shop scheduling in theory and in practice. Many of these have to do with objectives and penalties, the actual situation being dynamic rather than static as in many OR studies, and real life being more complex and random than accounted for in OR approaches. Most of the issues they list are still technical and operational in nature; even in those respects, reality is too complex to capture in OR techniques.

These problems have been recognized early on as well; Churchman (1967) discussed how wicked problems can be seen as beasts that OR research tries to tame by "carving off" pieces of these problems and finding rational and feasible solutions to these pieces. However, he argues that all OR manages to tame is the growl, which make the wicked problem no longer show its teeth before it bites. He argued that the morality of the OR profession depended on the extent to which it informs decision makers in which respects its "solutions" failed to the tame the wickedness of the problem.

More empirical studies of planning have listed a number of organizational factors that are not taken into account in OR planning research. More recently, Wäfler (2005) argues that planning, scheduling and control (PSC) in practice is a socio-technical system, based on the following findings:

Information to be processed is incomplete, ambiguous, dynamic and of stochastic nature,

²http://en.wikipedia.org/wiki/Job_Shop_Scheduling - accessed on August 2, 2010

- · Information flow follows feed forward as well as feed back and formal as well as informal structures,
- · Decisions to be taken are highly interrelated not only in content but also time wise,
- Goals to be followed are even if set clearly highly interrelated,
- Information processing and decision-making is distributed among many different (human and nonhuman) actors,
- Result oriented performance measurement and even more process-oriented evaluation of PSC practices are highly constrained,
- PSC duties are not clear, overlaps occur and organizational positions do not necessarily reflect duties, responsibility, and authority.

Based on these characteristics, Wäfler (2005) argues that it is difficult to isolate and allocate planning processes to a single planner, organizational unit or system; it is rather a process that is "a complex interplay of people, technology, and organizational structures, i.e. by a socio-technical system". As each point on his list is an issue discussed in chapter 3, it is clear that his view on planning as a socio-technical system applies to container terminal planning as well. Research on the human factor in production scheduling has existed for quite some time now, and many of these issues have been established before (for example, see (McKay et al., 1988)). More empirical work has been done, but unfortunately it has resulted in the same problems being stressed as before, while little improvement has been made in building better planning support systems: "At best, the majority of work is descriptive with some insights about what might be reasonable to include in production control practices and decision support systems. At worst, the research is anecdotal without any rigor or scientific value." (McKay and Wiers, 2006, page 53)

Bridging the gap

Based on the above discussion, it can be concluded that current planning research has little to offer in terms of improving the situation. In order to find suitable support from literature, it then becomes necessary to search in other fields of research. There are two reasons why this is so.

On the one hand OR approaches to actual planning prevail when it comes to the quantity of research, but offer relatively little value in practice according to literature. While researching OR studies in all kinds of fields is outside the scope of this project, it definitely applies to container terminal berth planning. First of all, the analysis above has shown that are discrepancies between the OR approaches found in literature and the situation at actual terminals. Secondly, in TBA experience, no automated berth planning tool is in use at any terminal. Finally, the various papers themselves offer no results from real life scenarios, or discuss how their proposed approach could even be implemented at a real terminal. Thus, it seems that when looking at scientific literature, there are no designs that are ready for being directly applied in practice.

On the other hand more empirical studies offer very little scientific rigor for the design of better scheduling support systems. Some argue that the latter is a direct result of the former: "Why is it that such a vast amount of research is being conducted and financial and intellectual resources being wasted generating useless solutions to unrealistic problems?" (Hurley, 1996) While this observation comes from within the scheduling research community, chapter 5 will show that similar questions have been raised by researchers from other supposedly practice-oriented disciplines as well. Either way, given the volume and actual impact of current berth planning research in OR disciplines and the complete abscence of any other literature on berth planning, the observation would seem to be valid for this field of research.

However, the fact that this issue is not restricted to planning offers opportunities. In the empirical research on planning that is present, some have focused on the way that actual planners make their decisions. For example, McKay et al. (1988) discuss how planners have to make concessions to the level of detail they take into account. They make use of simple logic because of the dynamic nature of their environment,

and avoid long-term detailed scheduling. As time progresses, they will then start to take more details into account. They have to deal with information that is possibly incomplete, ambiguous, biased, outdated and erroneous, but find ways around it. They use their intuition to fill in the blanks around what is happening on the floor using a mental picture of the situation. In many cases, they may even disregard the information present in their planning systems and base their decisions on their own expectations, rather than the system's (Fransoo and Wiers, 2005).

This description of how planners make decisions does not stand alone. Very similar observations have been made on decision makers in general. As scheduling literature offers relatively little rigor for designing planning support systems, it may be fruitful to explore literature on decision making in general to get a grip on how one can come to a good design for a scheduling support system.

4.4 Planning and human decision making

Planning can be related to decision making in general (Verbraeck, 1991); in many ways, it can therefore be considered similar or even equal to processes known as design and problem solving. This is argued in more detail in appendix A. Much planning literature adheres to the description of these processes as given by Herbert Simon (1996). The first stage of this process consists of determining an agenda, setting goals and the generation of possible courses of action. The second stage consists of evaluating these courses of action and making a choice.

Simon describes the artificial world as being centered on the interface between an inner and an outer environment. The inner environment is characterized by constraints and objectives, while the outer environment is characterized by fixed parameters. These parameters produce a set of possible worlds, each of which is then an alternative. When designing, one can consider possible worlds, in other words, worlds that meet the constraints of the outer environment. The goal of design is to find the world within this set of possible worlds that provides the best fit to the objectives and constraints of the inner environment. In other words, we can talk about design objectives, design constraints, and a problem space. Together, these form the *problem structure*.

Even relatively simple problems in reality are *ill-structured problems*, where goals can not be properly defined, and where it can not be evaluated whether actions contribute to meeting goals. As discussed above, in order to be able to make mathematical formulations of problems, OR methods need to make all kinds of assumptions and simplifications. Furthermore, even for some well-structured problems, they often need to make even more simplifications to make these mathematical problem computationally tractable.

Humans do the same: they have limits on what they can do, and therefore can not be assumed to be fully rational: "The capacity of the human mind for formulating and solving complex problems is very small compared to the size of the problems whose solution is required for objectively rational behavior in the real world - or even for a reasonable approximation to such objective rationality." (Simon, 1957, page 198) Instead, humans are said to make decisions under *bounded rationality*. Furthermore, both in human and machine computation, there are limitations in the number of alternatives that can be identified and evaluated. When it comes to humans, they are said to *satisfice*: they stop searching when they find a decision that is good enough.

When it comes to the way humans make decisions, the notion of mental pictures is very important. In empirical studies of human decision making, the concept of mental pictures that people use to structure problems in their minds has been very important. As was noted in section 4.3, this notion of mental pictures of a situation has been discussed in planning literature as well. The mental picture is related to the *problem representation*: even for problems with the same formal problem structure, multiple representations are possible that may lead to wildly different results in human decision making. \Rightarrow Principle 6.4: Enable decision support in all plan design stages

4.4.1 The mental picture: Situation Awareness

This notion of a mental picture that people use has been studied in dynamic decision making starting in the eighties and early nineties, originally in the military aviation domain (Endsley, 1995). The mental picture is dubbed *Situation Awareness* (SA). The notion itself and the design of artifacts that support it has been studied in all kinds domain since; examples include vessel traffic control (Wiersma, 2010) and railway control (Van den Top, 2010).

In situation awareness theory, an operator's mental picture is formed by combining the operator's goals, elements from the operator's current situation that are handled in short term memory with knowledge stored in the operator's long term memory. This long term knowledge is called a *mental model* and is stored in the form of *schemata*, which are patterns that can be matched to a current situation. *Scripts* are courses of action that can be linked to a schema and executed when a current situation is matched to the corresponding schema. In many cases, it will take a lot of experience to build up these schemata and scripts.

SA is something that is built up over time and then maintained. Furthermore, it has three levels (fig. 4.2). In order to successfully establish SA, it must be built up until the third level. The first level deals with the perception of the status, attributes and dynamics of relevant elements in the environment. This depends on an operator's access to data, the reliability of instruments, and the operator's level of attention. The second level is about understanding what the data and cues perceived mean in relation relevant goals and objectives. As this often requires combining various elements, it requires a good mental model. The third level deals with the projection what the elements will do in the future, at least in the short term. In all three stages, the relation with goals is very important.

When it comes to designing for situation awareness, Endsley et al. (2003) list a great number of design recommendations based on earlier experiences and analyses. The main themes being discussed deal with the limits on automation and the interaction between human and their support systems. Their main argument is that in order to make good decisions, humans require a good level of SA. Support systems should assist in developing human SA; many existing systems may even detract from it. Although they are not the only ones who give anecdotal evidence of how the interaction between human and computer may lead to (sometimes horrible) accidents (see for example Casey (1993)), they link these examples to their design recommendations. They focus on the perils when automating tasks without properly keeping the human in the loop, on the transparency and understandability of systems, and on operator control.

As a result, their main design recommendation is to make sure that the support system enables the operator to build and maintain situation awareness. Systems should support humans in perceiving the relevant elements in their environment, linking them to goals and projecting the future state of these elements in relation to these goals. This places high demands on the level of interaction between man and machine. They too argue that traditional systems that supply the human with advice have received more attention in research, and more research should be done on how to support humans in considering multiple interpretations of data, and in performing what-if analysis, encouraging them in considering multiple possibilities and perform contingency planning. This directly relates to the information used in supporting decision making and the uncertainty in it.

 $[\]Rightarrow$ Principle 6.4.1: Link information to goals and the extent to which they are met



4.4.2 The role of information and uncertainty in decision making

The notion that information is an important factor in decision making has been long recognized. For this same reason, many efforts have focused on the information itself and its quality, using many different viewpoints. Miller (1996) argues that the quality of the information is not a goal in itself, just a means: the quality relates to how the user consumes the information, to what decisions are made. Therefore, when identifying the level of quality in a number of quality dimensions, these dimensions will go beyond those solely based on the data itself. One could identify differences between inherent characteristics and pragmatic characteristics (English, 1999), with syntactic quality and semantic or pragmatic quality (Price and Shanks, 2004), or with intrinsic and representational characteristics (Wang and Strong, 1996). However, all types of quality are required for a good response to the information consumer. Bharosa and Gonzalez (Gonzalez and Bharosa, 2009; Gonzalez, 2010; Bharosa et al., 2008) have compiled such Information Quality dimensions based on work by Miller (1996); Wang and Strong (1996); Strong et al. (1997):

- Accuracy
- Timeliness
- Relevance
- Quantity
- Completeness
- Format
- Security
- Consistency

Problems with this notion of Information Quality are not always easy to solve; according to Bharosa, the solution space for IQ problems covers multiple layers: an organizational layer, a process layer and a technical layer. As a result, a solution has to address issues on all layers. According to Bharosa, even changes to the corporate culture may be required.

Furthermore, there are many IQ dimensions, and not always are they equally important. In some cases, need to be made. For example, as this thesis may prove, trade offs may exist between completeness and quantity. Information accuracy and timeliness may be at odds with one another: in many situations, it can be preferable to have less accurate information more timely than the other way around. This can be witnessed at terminals: for example, having a preliminary stowage list can greatly assist in berth planning, even if it is not accurate. This forces the planner to work with information that not be complete, or that may not be accurate.

 \Rightarrow Principle 6.3: Enable the handling of information with varying levels of information quality

Uncertainty

This trade off does allow the planner to make better guesses to the future situation. In other words: it enables him to reduce the uncertainty in the situation. In this case, they get the load plan and compare it to the usual procedure: can they expect more or less containers, is there anything out of the ordinary in the preliminary plan? While they can make forecasts based on the information, they will in turn not be accurate either. As time progresses, they may call in with the customer to check if there are any major changes to the schedule. They are thereby monitoring if any action is required. In fact, this approach for dealing with uncertainty is discussed in literature as well.

Agusdinata (2008) lists the available policy approaches to deal with uncertainty. In this case, an *adaptive* policy approach was taken. A policy can be instated immediately, after which the situation is monitored for future developments that may require revising the plan. Another approach that is common at terminals would be the delay approach: the planners can simply wait until more accurate information is available. However, it may then already be too late for action. Another way is to predict a single future and implement the optimal approach in that future. Alternatively, one can also design a policy that works well across a range of futures and then implement it. Finally, one can also do nothing until the uncertainty is resolved.

As discussed in section 4.4.1, considering multiple possible futures is an important way of dealing with uncertainty in dynamic systems. This notion has been used extensively in strategic planning (Bishop et al., 2007). For example, a well-known technique pioneered by Shell's strategic planning group is to assess dimensions of uncertainty, taking the two most important ones and then filling a 2x2 matrix with the *kernels* or scenario logic that corresponds to each cell. For instance, a terminal scenario where a first vessel is currently being serviced and a second ship is underway could be described as in fig. 4.3.



While this example is very operational in nature, at the Shell strategic planning group the use of these scenarios is of course much more profound and high-level. Based on these four cells, elaborate stories would be developed on each of the four scenarios, and policy that would particularly well in some scenarios would be implemented. Using this approach, Shell was able to predict glasnost by warning for this unknown person called Gorbachev, and could cash in on the following price drops. "Outcomes like these don't happen automatically. On the contrary, they depend on the ability of a company's senior managers to absorb what is going on in the business environment and to act on that information with appropriate business moves", said Arie de Geus, head of Shell's strategic planning group in the eighties.

For more operational problems, the notion of developing scenarios based on uncertainty dimensions is still useful. While more dimensions may have to be taken into account, this does not necessarily have to conflict with the approach described above. For example, the method used at Shell is formally a subset of a more general method called Morphological Analysis, in which the kernels can span more than two dimensions and more than two values on each dimension. Ways of dealing with the large of number of possible futures and selecting which to investigate have also been described in literature. For example, one can eliminate futures based on outcomes on different aspects of the kernel which are not likely to happen together; this approach is taken in a technique called Field Anomaly Relaxation (Bishop et al., 2007). What is most important though is that a set of possible futures is taken into account when making decisions, in such a way that no decisions are made that ignore these possible futures. In essence, this way of dealing is another example of an explorative technique, in this case to deal with uncertainty.

 \Rightarrow Principle 6.3.1: Enable the concurrent consideration of multiple scenarios and alternatives

4.5 The way forward: Interactive Decision Support

Section 3.5 discussed opportunities and challenges for improving berth planning. There are opportunities for improving berth planning on both operational and organizational levels. Most of the effort in container terminal planning research so far has been dedicated to the design of algorithms to 'solve' berth planning puzzles. The algorithms currently designed are not fit to deal with the complexities of berth planning reality. The goal of the efforts made so far has been to solve the puzzle, and these efforts have not proven to be of much use in actual scenarios. As long as the same approach is taken, it is not likely that the situation will improve much until the puzzle is actually solved in its entirety; this will not happen in the foreseeable future. Consequently, planners stick to their own methods and tools. Therefore, if we are to provide planners with support, we can not completely take over the decision process. It then logically follows that the only possible way of providing support must be a process where the planner and the tool both need contribute to the final decisions, and that therefore some form of interaction between planner and tool is required.

This chapter laid down a basis of what would be required from such a system: it should allow for a planner to interactively work with a support system that enables him to build up a picture of the situation and then make decisions based on that picture. It should enable him to get a grip on the uncertainties that are involved in berth planning, in such a way that good plans can be made despite the uncertainty. Finally, the various alternative decisions that can be made by the planner should be explored. As such, a symbiosis between planner and the system is required. The next chapter will describe what such a symbiosis between human and computer may look like, and what technology can support it.
Communication. The hardest part is the last four inches.

Chapter 5

The Computer Scientist as a Toolsmith II FREDERICK P. BROOKS, JR.

Intelligence Amplification: Theoretical foundations

The previous chapter discussed the approach that will be taken in this project: the creation of a tool that can be used by a planner interactively to support berth planning decisions. The tool has to perform this support by providing berth planners with information relevant to their decisions and enabling them to reason about this information. TBA is particularly interested in the possibilities for doing this using visualization techniques. This chapter will discuss what scientific theory exists that can provide some rigor to the process in which such a tool could be created. A number of theories have been selected from literature.

As the previous chapter suggested that there should be a symbiosis between man and computer, this notion will first be further elaborated on in section 5.1. Section 5.2 will discuss the experiences that have been gained earlier with similar techniques. Section 5.3 will discuss the problems in dealing with large information, and section 5.4 will discuss how visual techniques may be employed in order to help prevent these problems.

As discussed in section 1.2, this chapter should serve as two inputs for the design stage: Human Factors knowledge and Envisioned Technology. Although not all aspects of the theory can be regarded as part of Human Factors research, the notion of Intelligence Amplification was deemed to be the most relevant and inspirational theory for this thesis when it comes to human-computer interaction research. As such, it is given a great deal of attention here. For the Envisioned Technology input, this chapter discusses how visualizations might offer benefit in dealing with the large flow of information faced by planners. As these theories align on several aspects, the human factors and envisioned technology parts form a coherent whole.

5.1 Augmenting human capabilities: man-computer symbiosis

As discussed in section 4.1, most of the effort in container terminal planning research is dedicated to the design of algorithms to "solve" berth planning puzzles that are not fit to deal with the complexities of berth planning reality. As long as the goal of the efforts being made is to solve the puzzle, these efforts will fail to provide any benefit in real-life scenarios until the puzzle is actually solved. Consequently, planners stick to their own methods and tools. It was argued that for that reason, if we are to provide planners with support, we can not completely take over the decision process. It then logically follows that the resulting process is

one where the planner and the tool both contribute to the final decisions, and that therefore some form of interaction between planner and tool is required. As a planning tool can not solve planning problems and take over decision making, it should support the planner by extending his abilities to solve the planning problems.

5.1.1 Intelligence Amplification

This idea of interaction between tool and user is not new. In fact, time and again since the early days of what is now called Computer Science, several giants in the field have stressed the importance of developing tools that facilitate an interaction between computer and user. Perhaps it was Brooks (1996, page 64) who formulated the point most eloquently in his acceptance speech for the ACM Allen Newell award:

If indeed our objective is to build computer systems that solve very challenging problems, my thesis is that

IA > AI

that is, that intelligence amplifying systems can, at any given level of available systems technology, beat AI systems. That is, a machine and a mind can beat a mind-imitating machine working by itself.

The main point of his speech was that Computer Science was an unfortunate, and in fact a mistaken name. He argued that it falsely propagated the view that it is a discipline dealing with *discovery* rather than with *making things*: he believes Computer Science to be a *synthetic* discipline. He believes that many practitioners have forgotten that their main role is to be a *toolsmith*. In doing so, they "tend to forget their users and their real problems, climbing into our ivory towers to dissect tractable abstractions of those problems, abstractions that may have left behind the essence of the real problem." (Brooks, 1996, page 62)

Brooks argued that the computer science discipline has disproportionately invested money, but more importantly the intellectual effort of a generation of computer scientists in what he called Artificial Intelligence methods, which he believes mostly deal with these abstractions of real problems. This has barred progress on other promising research opportunities. He believed at the time that the wild expectations of the AI discipline had vanished over time, as researchers began to see the limits of their approaches.

At that point, he felt it appropriate to stress the importance of building things that help people in other disciplines, a point he had made 20 years earlier in the same way. This time, he posted his bet on the victory of IA systems over AI systems. He illustrated his bet using the example of computer chess: "Someday a computer may beat the world champion in chess. When that day comes, I should like to see the world champion equipped with a powerful and suitable IA chess tool, and then play against the AI system. I'll bet on the IA team." (Brooks, 1996, 64)

IA in chess: the triumph of machine over man

Chess has been a very interesting research problem throughout the 20th century. Its intractability has provided AI researchers with many avenues in which the problem could be attacked. While it was unthinkable at first that a machine could play chess at any level, it did not last long until researchers began to investigate the possibilities. Early contributions (Shannon, 1950; Bernstein and Roberts, 1958) only provided very rudimentary play, but soon people started to believe that computers might eventually become better at the game than humans.

Still, International Master David Levy felt confident enough in 1968 to make a famous bet that no program would be able to beat him in a chess match for 10 years.¹ Chess matches consist of a number of games. Indeed Levy had no problems at first in consistently beating the programs, but his final match marked the first time that a program managed to earn a point against him, taking away one draw and one win. The program was much stronger than Levy had anticipated ten years earlier. Still, it took until 1989 for IBM's Deep Thought chess computer to beat Levy in a match.

Two years after Brooks' speech, which was in fact held in 1994, a famous match occurred between another incarnation of IBM's chess computer called Deep Blue and World Chess Champion Garry Kasparov. When Kasparov played Deep Thought in 1989, he won both games of a two-game match. This time, he played a six-game match, and lost the first game but went on to gain three wins and two draws. One year later, an updated version of Deep Blue outfitted with a greater computational capacity defeated Kasparov with a score of 3½-2½. While one might initially perceive this feat as the triumph of machine over man, further developments in chess made it obvious that the role of man was not yet played out, even for such a problem which is easily formalized.

After this barrier was broken, chess players were coming up with tactics to exploit the weaknesses in computer chess programs, trying to even the balance once again. Kasparov instead pursued the use of computers in chess by creating centaur chess, where a team of one man and one chess computer would play another team of one man and one computer. Still, this was not challenging enough and in 2005 the first internet freestyle chess tournament was held.² The rules were that there were no rules. Teams would be allowed to consist of any combination of men and computers, and the only protocol was the time schedule in which moves were to be submitted.

IA in chess: the triumph of process over power

Lured by the substantial prize money, several teams consisting of very strong grandmasters equipped with chess-specific supercomputers entered the tournament. Some teams played anonymously however, and one of these anonymous teams rose up to the final with a playing style that was so good, many believed it was Kasparov who had entered the tournament.

In the final, the 'dark horse' team *ZackS* played a team consisting of Russian Grand Master Vladimir Dobrov, aided by another colleague with a rated strength of over 2600 ELO points and of course by strong chess computers. For reference, a bright beginner may have a rating of about 1000 points.³ A master usually has at least a rating of 2200, and the strongest player at the moment has a rating of 2826 points.⁴

The ZackS team won the match convincingly; it turned out to be a team consisting of two US players with ELO ratings of a mere 1381 and 1685 points, and three inexpensive personal computers that were not fast even for desktop standards at the time, and that were each equipped with basic but different chess programs.

The winners explained that they were very careful in selecting the positions that each specific chess program was to examine, going on their experiences and instinct and taking the strengths and weaknesses of each program into account. They deemed their in-depth knowledge of the various chess programs they used to be one of their key strengths: "Once we established our possible candidate moves (usually three or less, but sometimes more) we began to investigate the lines extensively. Zack would analyze a few lines and

¹http://en.wikipedia.org/wiki/David_Levy_(chess_player)#Computer_chess_bet - accessed on February 7, 2011

²http://www.chessbase.com/newsdetail.asp?newsid=2467 - accessed on February 7, 2011

³http://en.wikipedia.org/wiki/Elo_rating_system#Performance_rating - accessed on February 7, 2011

^{*}http://en.wikipedia.org/wiki/Magnus_Carlsen - accessed on February 7, 2011

I would analyze a couple of different lines. When either of us found a strong continuation we then looked at it together, comparing the lines between the different engines (mainly between Shredder 8 and Fritz 8). I believe this method of move selection, along with our opening preparation and specific knowledge of the chess playing programs that we used, provided us with a solid foundation in which to move forward during our games.³⁵

Kasparov was asked repeatedly whether he was part of the team and kept on denying, concluding that it was the skill of the players in coaching their computers on which positions to examine is what earned them the victory: "Weak human + machine + better process was superior to a strong computer alone and, more remarkably, superior to a strong human + machine + inferior process."⁶ Furthermore, Kasparov concluded that while the goal of making chess programs play well has been met by focusing on computational capacity and brute-force strategies, the original and more interesting goal of making computers play like humans has been set aside. "While brute force is good enough for chess, the real world is infinitely larger,"⁷ Kasparov commented in 2010. Much like Brooks fifteen years before him, he lamented on the loss of intellectual capacity by focusing on the wrong puzzle.

IA: an old idea

The story discussed above shows some insight into what is meant when it is said that tools should be designed that let user and computer work together. However, Brooks was not the first to raise the point. In fact, while the origins for the idea can even be found in the 1940's (Bush, 1945), the first uses of terms like "Intelligence Amplifier" can be found in the 1950's and the first visions and implementations of what it could entail were made in the 1960's.

When computers were still viewed mostly as machines to do computations, some people managed to look beyond and envision a more interactive use of these machines. One of the most groundbreaking research efforts in computer history was originated at the Stanford Research Institute (SRI) and sponsored by ARPA. Among the key persons involved were J.C.R. Licklider from ARPA and Doug Engelbart at SRI. Licklider himself envisioned a "man-computer symbiosis" (Licklider, 1960). While this speculative paper is mostly remembered for discussing for the first time the ideas that would later evolve to become the internet, it also foresaw several developments in how men would interact with these computational machines, going beyond what was possible at the time.

IA: early concepts

Licklider called for research on two main aims. The first harks back to what was discussed in the freestyle chess example. Licklider argued that machines should not be mere computational machines that solve formulated problems, but that they should be brought in to facilitate formulative thinking as well. The second aim was to make it possible for man and computer to "cooperate in making decisions and controlling complex situations without inflexible dependence on predetermined programs". He called for a set of "principles of man-machine engineering" to facilitate the design of such systems.

Although he recognized the possibility that at some point in the future, dominance for the entire problem solving process might be conceded to the computer, he argued that there would be "a fairly long interim

⁵http://www.chessbase.com/newsdetail.asp?newsid=2467 - accessed on February 7, 2011

⁶http://www.nybooks.com/articles/archives/2010/feb/11/the-chess-master-and-the-computer/?page=2 accessed on February 7, 2011

⁷http://blogs.forbes.com/oliverchiang/2010/11/02/garry-kasparov-the-last-revolutionary-technology-was-the-apple-ii/- accessed on Februari 7, 2011

during which the main intellectual advances will be made by men and computers working together in intimate association". In this intimate cooperation, the machines would function by testing models against data designated by the human operator, interpolating, extrapolating, transforming and plotting data, even in several alternative ways if the human is not sure what he wants. The computer would "convert static equations or logical statements into dynamic models so the human operator can examine their behavior." The humans would have a role in "defining criteria and serving as evaluators, judging the contributions of the equipment and guiding the general line of thought".

Licklider perhaps found a kinship in the ideas of Doug Engelbart, and funded his research. The most famous output of this collaboration would be a demonstration now sometimes referred to as *The Mother of All Demos.*⁸ This demonstration would feature the introduction of the computer mouse, video conferencing, teleconferencing, email, hypertext, word processing, hypermedia, object addressing and dynamic file linking, bootstrapping, and a collaborative real-time editor. These technological inventions played a major role in bringing computer science closer to their vision of its potential.

However, there were elaborate philosophies behind these innovations that were maybe not as embraced as warmly as the innovations themselves: "People could understand your easiest ideas, like the mouse and pointing and hyperlinking, but they had a lot of trouble understanding your really big ideas, like augmenting the intelligence of groups of adults. Your thinking about how this is all going to turn out is correct but it's still yet to happen." said to Engelbart by Alan Kay, another major figure in the development of computer science in general and human-computer interaction in particular.⁹

At an early stage, Engelbart's ideas already revolved around the concept of "intelligence amplification" (Engelbart, 1962). He attributed the term to Ashby (1956), who specifically discussed it in relation to problem solving activities. Engelbart's concepts were further inspired by ideas from Bush (1945). He explained his intentions by explaining that "by 'augmenting human intellect' we mean increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems." Already then, Engelbart emphasized the ambition to assist in solving complex problems: "We do not speak of isolated clever tricks that help in particular situations. We refer to a way of life in an integrated domain where hunches, cut-and-try, intangibles, and the human 'feel for a situation' usefully co-exist with powerful concepts, streamlined terminology and notation, sophisticated methods, and high-powered electronic aids." (Engelbart, 1962)

 \Rightarrow Principle 6.1: Exploit the way in which human and computer can add to each others' capabilities

IA: the benefits of non-automation

The notion that users and computers need to work together is not one that is strictly necessitated by the lack of computers' ability of performing tasks. Endsley et al. (2003) argue that a guideline is to automate only if necessary. Improvements often don't come from automation itself but from improved information and material process flows and the reduction of unneeded steps. The investigation of work processes, information and material flows are often triggered by the decision to automate a task. The added insight that was a prerequisite to the automation of the task could have improved manual execution as well. This should be discounted for when evaluating improvements of automation.

Furthermore, executing a task over and over again provides experience with this task. By reflecting on this experience, new insights on how to perform the task may be derived. By automating the task, this

^{*}http://en.wikipedia.org/wiki/The_Mother_of_All_Demos - accessed on February 7, 2011 *http://www.visualinsight.net/engelbart_kay.html - accessed on February 7, 2011

experience is not built up. This may be detrimental to the improvement of task execution processes.

5.1.2 Complex problems

There are and have been many developments in supporting decisions over the past few decades: Management Information Systems (MIS), Enterprise Information Systems (EIS), Decision Support Systems (DSS), Expert Systems, Group Support Systems (GSS), Knowledge Management, Business Intelligence (BI), Business Analytics (BA), OnLine Analytical Processing (OLAP) are generally all some type of interface between human and data that have the goal of assisting the human in extracting information from the data. While the definitions may overlap and a general typology of all these systems is hard to define (for example, see discussions in Carlsson and Turban (2002) and Alter (2004)), in general all these movements deal with systems that provide data, information or knowledge to human users. For this project, we follow the argument of (Alter, 2004) when he said that "decision support is not about tools per se, but rather, about making better decisions within work systems in organizations." These work systems are often not readily formalized.

According to Hevner et al. (2004), Design Science research for Information Systems addresses *wicked problems* (Brooks, 1987, 1996; Rittel and Webber, 1984) that are characterized by ill-defined and unstable requirements, constraints and contexts, complex interactions between the problem and the solution. More importantly, Hevner emphasizes that these problems are characterized by a critical dependence on human cognitive abilities and human social abilities to produce effective solutions.

This reliance on human cognitive abilities to solve complex problems is not just a "second best"-solution. A school of thought lead by the German psychologist Gerd Gigerenzer focused on human *heuristics* "that make us smart". (Gigerenzer and Todd, 1999) They continued on a research trail explored by Tversky and Kahneman (1974) on heuristics: simple decision making rules employed by humans. However, whereas Tversky and Kahneman focused on the *biases* that negatively affect our ability to make good decisions, Gigerenzer focuses on the ability of human experts to make good decisions based on simple rules (Gigerenzer et al., 2007). They argue that humans are well adapted to their tasks. Similar sentiments can be found for example in the informational visualization field (which will be discussed in section 5.4), where practitioners work under the assumption that providing humans with a good way of inspecting information will enable them to make good decisions.

Going back to complexity, the idea conveyed by Brooks (1996) is that system design problems bring about issues of *arbitrary complexity*. In disciplines likes physics or biology, practitioners believe that the natural world is *not* arbitrary, that there is an underlying logic to the way things are that can be found when you search long enough. In disciplines like mathematics, practitioners deal mostly with problems that can be simply formalized and readily abstracted. Brooks therefore argues that the issues of arbitrary complexity found in system design problems are not found in these other disciplines.

5.2 Early experiences: Decision Support Systems

Much like earlier ideas on human-computer symbiosis, a movement at the end of the 1970's was offset against the growing interest in the development of AI methods. Researchers departing from a broader systems thinking point of view were interested in the creating of Decision Support Systems (DSS): "Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semistructured problems". (Keen and Morton, 1978) According to Keen and Morton (1978) a decision support system should support decision makers rather than replace them. He placed an emphasis on the interactivity between decision maker and DSS.

DSS novelties: promise and realization

According to Carlsson and Turban (2002), the early definitions of DSS focused on four novelties: methods for dealing with unstructured or semi-structured problems, interactive systems, user-orientation, and separation of data and models. The supposed implications of this approach included the promises that decision-makers could deal with more difficult problems than possible under an OR or traditional management theory banner, that they could make more reasoned decisions without optimization or advanced modeling, and finally that they could make more systematic use of their existing knowledge and experience.

Carlsson and Turban argue that much experience has been gained over the past three decades in building decision support systems. However, Carlsson and Turban argue that the original promise did not fully come true, and list a number of reasons that are related to people rather than technology:

- People have cognitive constraints in adopting intelligent systems,
- People do not really understand the support they get and disregard it in favor of past experience and visions,
- People cannot really handle large amounts of information and knowledge,
- People are frustrated by theories they do not really understand,
- People believe they get more support by talking to other people (even if their knowledge is limited).

When decision makers have much past experience that they believe is not represented in the system, it may be more logical for them to turn to this past experience rather than trusting the system. The point made in section 5.1.1 was that human and computer need to augment each others' capabilities: there needs to be a symbiosis.

When information is presented by a computer system 'as is', there may be issues for the human in reflecting and evaluating it. Ackoff (1967) argued that "no MIS should ever be installed unless the managers for whom it is intended are trained to evaluate and hence control it rather than be controlled by it." Neerincx et al. (2008) emphasized the *trust* that a user has in the system: "If users rely too much or too little on human or technology, performance will be suboptimal. Appropriate trust depends on understanding of capabilities of the system, colleagues, and oneself. Users are not very good at estimating how much to trust a machine." As was discussed in section 5.1.1, Licklider (1960) argued in essence that humans need to be the directors of the decision process by guiding and evaluating the system's performance. They can not adequately perform this role when they do not understand the system. The result will be suboptimal at best, and may even lead to disuse of the decision support system.

 \Rightarrow Principle 6.1.1: The planner as the director of the decision process: ensure system transparency

 \Rightarrow Principle 6.1.2: The planner as the director of the decision process: enable planner control

User-system-builder interaction

A design that is based on a human-system interaction therefore needs to take the problems listed above into account and counter them. In essence, just like the user requires an understanding of the limits of the system, the system must have some understanding of the users' limits embedded into it. In general, this can be done by adaptively building systems that take the user into account (Keen, 1980) or by building adaptive systems that themselves learn more about the user (Kobsa, 2001). There has been extensive experience with the former. Keen (1980) describes how there is an adaptive relationship between builder and system and the users, their tasks and the organization. The way in which users execute their tasks may influence a system, but subsequently the way users perform their tasks is in turn influenced by the system.

Users may come up with idiosyncratic ways of using tools that were not predicted when the system was designed. These ways of using tools may be *faithful* or *unfaithful* to the spirit of the tool design (DeSanctis and Poole, 1994). Some feel (DeSanctis and Poole, 1994) that all human action is performed in pre-existing social structures. The *appropriation* of new technology depends on these structures. "Because the new structures offered by technology must be blended with existing organizational practices, radical behavior change takes time to emerge, and in some cases may not occur at all."

According to Keen (1980), users may feel that tools are not really used for decision making but for supporting an organizational process. The true benefits may well lie in flexibility, improved communications, insight and learning. Understanding how these benefits may come about as a result of the system is then key in adaptively shaping a good design.

Choice automation: decision biasing

As opposed to definition of DSS given above, (Endsley et al., 2003) note that many Decision Support Systems were designed to advice the user on a course of action or assigned scores to various alternatives: they automated the choice phase of the decision cycle. Endsley et al. (2003) note that this approach may elicit problems of decision biasing when giving support in this way. The information being given by the machine simply becomes another piece of information to deal with, only adding to the information already available rather than being linked to it. Endsley et al. (2003) call this a serial system, as displayed in fig. 5.1.

When both the human and the machine can come up with a decision, and both have a certain degree of reliability in their decisions being 'correct', the cue given by the system has a big influence on the decision taken by the human. The reliability of such a serial system is lower than the reliability of either machine or human reliability independently. In order to be able to employ a decision support system in a parallel fashion, it is paramount that the user can understand how the information is processed by the machine. He can then select a decision based on his own understanding of the data and on his understanding of the system.

5.3 Information overload

Section 5.2 discussed that one of the problems found in applying Decision Support Systems was that people cannot handle large amounts of information and knowledge. While the starting point for many information system designers is to provide information to its users, this may not always yield the desired effect. This problem was already foreseen in MIS literature at an early stage: "I do not deny that most managers lack a good deal of information that they should have, but I do deny that this is the most important informational deficiency from which they suffer. It seems to me that they suffer more from an *over abundance of irrelevant information*." (Ackoff, 1967)

Simon (1996) stresses the importance of finding the limiting resource; he argues that often a solution focuses on the wrong resource and, as a consequence, the problem remains unsolved. When it comes to information overload, Simon (1971, page 40-41) phrases the point in an almost poetic way:



Figure 5.1: Parallel and serial systems reliability *Source: Endsley et al. (2003)*

When we speak of an information-rich world, we may expect, analogically, that the wealth of information means a dearth of something else - a scarcity of whatever it is that information consumes. What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention, and a need to allocate that attention efficiently among the overabundance of information sources that might consume it.

Endsley (2000) discussed the concept in terms of an 'information gap', where this gap denotes a mismatch in the amount of data produced and our ability to process this data into information needed for decision making. This is displayed in fig. 5.2.



Based on the idea that the problem faced by decision makers may be an over abundance of information rather than a shortage of information, Ackoff (1967) concluded that the two most important functions of a MIS are then *filtration* (or *evaluation*) and *condensation* of information. However, history has shown that this is something still to be achieved. Simon (1996) discussed how the first generation of Management Information Systems failed to protect managers from this stream of distractions of their attention by blindly providing more and more information. "The real design problem is not to provide more information to people but to allocate the time they have available for receiving information so that they will get only the information-distributing systems but intelligent information-filtering systems." (Simon, 1996, page 144) At the time of writing the third edition of his book, he concluded that "the lesson has still not been learned." (Simon, 1996, page 144)

Information reduction

As discussed above, Ackoff (1967) concluded that filtering and condensing information are two important functions of information systems. More, generally, the goal is to make sure that when decisions need to be made, decision makers can make good decisions in the time available. "The proper aim of a management information system is not 'to bring the manager all the information he needs', but to reorganize the manager's environment of information so as to reduce the amount of time he must devote to receiving it. Stating the problem in these two different ways leads to very different system designs." (Simon, 1971)

However, protecting users from this stream of information has its own pitfalls. Ackoff (1967) argues that in order for someone to be able to know what information he needs and which he does not, he must be aware of each type of decisions he should make and he must have an adequate model of each. He concludes that these conditions are seldom satisfied. By the same token, if we want to design a computer system that filters information, it must be aware of these things as well. However, formalizing this knowledge and entering it into a computer may be a very hard thing to do.

This lesson was learned in the HCI community as well. Endsley et al. (2003) state that the filtering and reduction of information should be beneficial to Situation Awareness. According to Endsley et al. (2003), many systems have been developed under this assumption that use an information filtering approach to reduce information overload. However, they argue that for a number of reasons, this approach actually reduces situation awareness.

Their first argument is that situation awareness is developed over a period of time. Information filtering often made it impossible to build up a mental overview of the situation; instantaneously presented information is not sufficient when decision makers have to be predictive and proactive. Secondly, they stress the importance of planning ahead. Finally, individual users may use different types of information to make their decisions.

As a result, Endsley et al. (2003, page 88) argue for another approach that involves an interactivity between human and computer that is similar to the one that was discussed in section 5.1: "Presenting information in a clear and easy to process manner, with the operator in charge of determining what they will look at when, is far better than computer-driven strategies for providing only subsets of information."

Endsley et al. (2003) furthermore argue that even information cueing, which consists of highlighting those areas or pieces of information that the tool deems important, is prone to create problems of attention bias. They favor an approach where users can use their own senses more effectively. For example, rather than highlighting relatively important pieces of information in a cluttered display, the user should be provided with a means of systematically removing unwanted information. In that way, they can unclutter the display and better see what they are looking for.

 \Rightarrow Principle 6.1.3: Prevent information overload: planner-controlled information filtering

5.3.1 Solving the overload

As discussed above, information overload issues have not yet been solved in the current generation of decision support technology; information technology becoming more widespread has aggravated the problem rather than alleviating it. To some researchers, solving this problem for the next generation of decision support technology is a prominent item on the agenda: "The first target for some sort of intelligent new generation of DSS technology should be the overwhelming flow of data, information and knowledge produced for the executives from an increasing number of source." (Carlsson and Turban, 2002, 2).

One of the problems in this first generation of Decision Support Systems was that it was restricted in its possibilities for information input and output. Like most software of its time, "Decision Support was of necessity built around 'numbers'" according to Keen and Sol (2008, page vii), who argued for a support that "rests far more on images, dynamic visualization and communicative display." Along the same lines, Brooks (1996, page 64) argued that "in getting information from the mind back into the machine, one thing for certain is that character strings are not usually the natural or right mechanism."

In order to solve the overload, Brooks (1996) stressed the need to exploit human's broadest-band channel. "When we decide to harness the powers of the mind in mind-machine systems, we study how to couple the mind and the machine together with broad-band channels." (Brooks, 1996, 64) While these broadband channels may also include haptic, auditory and tactile interfaces, the experiences gained in the visualization of information provide us with a good candidate to alleviate the problems associated with information overload.

Again, this idea was nothing new. Sutherland (1963) made Sketchpad, the first working implementation of software that communicates visually between man and machine. Kay noted that Sketchpad was built on "the last system large enough to have its own roof" and that most computers at the time of his lecture - twenty five years later - were capable of doing the same, it was "just that nobody was doing it".

5.4 The last four inches: visualization of information

Graphics interfaces started to become common in the 1990's, and since then considerable advances have been made in developing graphical interfaces between man and computer. Along with a growing scientific interest in visualization (Rosenblum, 1994), spurred by the birth of scientific visualization as a discipline in the late 1980s more attention was given in the scientific community as to how effective visualizations may be designed. The visualization of information as has a much longer tradition in print (Tufte, 1983) that was embraced by the computer visualization community. A distinction can be made in *scientific visualization* as a discipline dealing with the visualization of physical objects and *information visualization* as a discipline dealing with the visualization of abstract or non-physical data (Spence, 2001). Therefore, information visualization is the discipline of choice when it comes to communicating large amounts of abstract data.

A number of steps can be distinguished in producing a visualization from this raw data. Card et al. (1999) defined a basic reference model for this process. First, raw data has to be transformed: it may be filtered or structured. This transformed data is then mapped onto a set of visual constructs, which may consequently be shown in a set of views, which is navigated in some way - usually by the user. In fact, the user may have a role in each of these steps (fig. 5.3).



Source: Card et al. (1999)

Effective HCI has been an important issue for visualization researchers (Sutherland, 1966) and still is (Johnson, 2004). It is important that users can effectively interact with visual data, especially when there is an overabundance of data. Visualization researchers have learned that "designing effective visualizations requires a good understanding of the subject matter."(Johnson, 2004) The mapping between items in the visualization and objects in reality needs to be very clear. In other word, understanding how humans work with visualization is a key problem in visualization research, which Brooks (1996) showed in the way displayed in fig. 5.4.



Figure 5.4: The hardest part of communication: the last four inches *Source: Brooks (1996)*

As was discussed in section 5.3, the key challenge for good decision support tools is to provide good facilities for the user of the tools to filter and condense information. When navigating the information, the user therefore needs to be able to select which information to filter and how information can be condensed. One off-cited design recommendation on how to let users interact with visual data can be found in the mantra offered by Shneiderman (1996): "Overview first, zoom and filter, then details-on-demand".

The display of large data sets

More broadly speaking, what is important is that users can examine relevant details, while still retaining a good overview of the context of these details. This is in line with the view of how Situation Awareness is

built up posed by Endsley et al. (2003). Visualization research has focused on what are called *focus+context*-techniques. An early example is the concept of fish-eye graphics (Furnas, 1986). An example of popular applications of this technique include fish-eye menus (Bederson, 2000).

The concept of focusing on details while keeping the entire context in the same view was researched in more detail in the 1990s. Examples include the *perspective wall* (Mackinlay et al., 1991), the *table lens* (Rao and Card, 1994) and the *hyperbolic geometry browser* (Lamping et al., 1995). These are discussed in more detail in appendix B.

More generally, these techniques are *distortion*-oriented visualization techniques that have the aim of exploring large volumes of data. Leung and Apperley (1994) give a taxonomy of these techniques that is displayed in fig. 5.5.



Figure 5.5: A taxonomy of presentation techniques for large graphical data spaces Source: Leung and Apperley (1994)

In turn, distortion techniques are just one of many techniques that can be used to deal with information overloads. Ellis and Dix (2007) applied the term 'clutter reduction' to techniques designed to show large data sets on small displays in ways that make the acquisition of knowledge as easy and enriching as possible. Ellis and Dix designed a taxonomy of these clutter reduction techniques that is displayed in fig. 5.6

	clutter reduction technique	examples
appearance	sampling	[15, 16, 18, 40]
	filtering	[1, 3, 8, 39, 45]
	change point size	[4, 15, 39, 52]
	change opacity	[22, 27, 32, 49]
	clustering	[12, 23, 33, 54]
spatial distortion	point/line displacement	[3, 29, 46, 47, 50]
	topological distortion	[1, 11, 31, 34, 42]
	space-filling	[4, 22, 44]
	pixel-plotting	[26, 30, 41]
	dimensional reordering	[38]
temporal	animation	[14, 27, 47]

Figure 5.6: A taxonomy of clutter reduction techniques *Source: Ellis and Dix (2007)*

Exploratory character of tasks

Other recommendations by Shneiderman (1996) stresses the importance of history, of the relationships between items and of the extraction of sub-collections. What he is essentially describing is that users interact with visualizations in an exploratory way. He argues that information exploration is a process with many steps; allowing users to retrace their steps is considered important. He also argues that visual displays have opportunities for showing relationships "by proximity, by containment, by connected lines or by color coding." (Shneiderman, 1996, page 340) After exploring a data set, users may find that a selected subset is useful for further processing; this should be easily facilitated.

Visualization of uncertainty and the salience of visualizations

Representing uncertainty is still identified as a major issue on the visualization research agenda (Johnson, 2004). Endsley et al. (2003) have shown some ways in which uncertainty can be visualized. They placed an emphasis on the idea that the level of salience assigned to uncertainty of items in the visualization should be such that it does not detract from the information itself. For example, in fig. 5.7 they show various ways in which the uncertainty of the location or the projected location of an aircraft may be visualized.

Endsley et al., page 126 argue that the first proposed visualizations of location and projected location show an unfortunate side effect. "The information about which the most uncertainty exists becomes the most prominent on the display, drawing the operator's attention to it." The rings and the fan display exhibit this problem, and Endsley et al. tried to ameliorate this by providing more salience to the most certain information and less *salience* to the more uncertain information.

They argue that salience is the extent to which a visualized item draws attention to it. They explain this by arguing that red colors or flashing lights are more likely to draw attention than other features. Part of their design philosophy is that the problem of *misplaced salience* should be prevented; attention should not



Figure 5.7: Multiple ways of showing uncertainty in position (a-c) and projected position (d-e) Source: Endsley et al. (2003)

be diverted from important items in the visualization to other, less important items because of misplaced salience. A problem frequently found is that in the overall visualization, so many items are given salience that they are fighting each other for attention, displaying what Endsley et al. (2003) call the *Las Vegas Strip phenomenon*.

5.5 Theoretical foundations: round-up

This chapter discussed various scientific literature that will guide the design of the prototype. Most attention was given to the notion of Intelligence Amplification, and how decision support should be given by having man and computer interact with each other in a symbiotic way. There has been earlier experience with these type of systems in the field of DSS, and these experiences have led to the notion of information overload: the goal is not to distribute as much information as possible, but rather to create an environment where the decision maker can allocate his attention better to the most relevant pieces of information, and where he can more easily receive or consume the information.

Finally, some literature on information visualization was discussed, with a specific focus on how it can be employed to solve this information overload. Although this last part did not deemed to warrant a design principle, the general notions where used in the prototype design. In this way, this chapter did not only provide a theoretical foundation for the design of the berth planning prototype, but also proved to be inspirational with regards to the creative process.

Together with the previous chapters, which discussed the application field and the problem analysis, this chapter stands at the basis of several design principles for the design of a berth planning decision support tool. These principles have been listed throughout the text, and will be gathered in the next chapter. Thus, there is a direct and declared link between the problem analysis, the foundational theories and the design of the tool. Therefore this chapter now closes the input stage of the design process. The next three chapters will deal with the actual design, by defining the design principles and by documenting the prototype and its evaluation.

Tactics is knowing what to do when there is something to do. Strategy is knowing what to do when there is nothing to do.

SAVIELLY TARTAKOWER

Chapter 6

Design Principles

This chapter lays down a set of design principles for the design of a berth planning tool. As discussed in chapter 1, the duration of the design stage in this project is insufficient to complete a number of design iterations. To preserve the insights gained from the analysis phase, a number of principles based on these insights are defined. These principles can then shape the iterations for further development cycles. Before the principles themselves are presented, the manner in which design principles are used here will be motivated and discussed first.

Principle-based design: method and motivations

As is often the case in information system design projects (Hevner et al., 2004) the design of the new system is based on a relevance cycle and a rigor cycle. As explained in chapter 1, in the situated cognitive engineering method the relevance cycle consists of a problem analysis. For HCI system design projects, this analysis often focuses on environment, tasks and users (Sharp et al., 2007; Endsley et al., 2003). This was done in chapter 3. The rigor cycle consists of a examination of available human factors research and technology. This was done in chapter 5.

For many information system design projects in general (Hevner et al., 2004; Markus et al., 2002) and HCI projects in particular (Endsley et al., 2003; Neerincx et al., 2008; Sharp et al., 2007) iterative design approaches are advocated. It is hard to get the whole design right the first time, and it is well-recognized in literature (Sharp et al., 2007; McConnell, 1996) that it is often not even possible to come up with a set of concrete requirements after the first problem analysis. Working in an iterative manner is supposed to assist in building up these requirements. However, as was discussed above, the length of this project is insufficient to complete a number of development cycles. When just building one prototype, the insights derived from the analysis run a risk of getting lost in subsequent cycles if they are not properly documented in order to be retained or even transferred to other designers.

For this reason, the most important of these insights are incorporated in a set of design principles. Their aims are to structure the analysis of the previous chapter, and to guide the design of an actual prototype implementation without specifying a concrete set of requirements just yet. Additionally, their focus should not be on explicit solutions to problems: they should not constrain future creativity. They should be general in nature: while there may be all kinds of differences between terminals that might have to be taken into account in full systems, these principles should hold for all terminals. As such they can be seen as strategical design choices, where the choices made in designing the actual prototype are more on a tactical level.

Principle-based design: project position

The use of principles is common practice in design communities. For example, this project used literature defining design principles for user interface design (Shneiderman, 1997), for designing for situation awareness (Endsley et al., 2003) or for designing netcentric crisis response tools (Bharosa, 2011). Often, these principles are formulated by scientists who have become 'gurus' in a certain field and are meant to guide fellow designers. In this project, the intended use of the design principles is not exogenous but endogenous: the definition of the principles and the design of the full system are done over the course of the same project. In this way, it becomes possible to shape the design of the full system before starting the first development cycle, while still preventing the creativity in this cycle to be constrained by placing very formal requirements upon it.

Overview of design principles

In total, 10 design principles were defined. These principles all relate to the design of a berth planning tool, but have been formulated in a very high-level way. They are all based on the previous chapters; links to their sources are listed for each principle, along with a brief explanation and rationale. Before discussing these principles one at a time, table 6.1 will give an overview of the principles that were defined.

Table 6.1: Overview of Design Principles

- 6.1: Exploit the way in which human and computer can add to each others' capabilities
- 6.1.1: The planner as the director of the decision process: ensure system transparency
- 6.1.2: The planner as the director of the decision process: enable planner control
- 6.1.3: Prevent information overload: planner-controlled information filtering
- 6.2: Provide an architecture that facilitates different forms of the planning task
- 6.3: Enable the handling of information with varying levels of information quality
- 6.3.1: Enable the concurrent consideration of multiple scenarios and alternatives
- 6.4: Enable decision support in all plan design stages
- 6.4.1: Link information to goals and the extent to which they are met
- 6.5: Enable decision support that acknowledges the existence of other interrelated planning decisions

6.1 Exploit the way in which human and computer can add to each others' capabilities

Explanation: Tool and planner each will have different capabilities. They should add to each other. *Source:* Section 5.1.1

Rationale: In cases where a task requires lots of information to be handled quantitatively, the tool should handle it, while the human should be in control of how this is done. When certain menial tasks have to be done, if possible it should be automated. On the other hand, when a computer has weaknesses on a task the human should be able to seamlessly take over. The main idea is that tool should augment the human at those places where he is weak, and the other way around. Having the human interact with the information in a way that makes it easier to reason about it than under current conditions may improve planning.

6.1.1 The planner as the director of the decision process: ensure system transparency

Explanation: The way in which the tool comes to its output should be transparent to the planner: they have to be able to evaluate its contribution and whether it makes sense or not, given the situation. *Source:* Section 5.2

Rationale: The planner needs insight into the situation. As the picture of the situation in the tool will be incomplete, the planner will still be the executive when it comes to making planning decisions, not the tool. It was argued in section 5.1.1 that planners need to be in charge of the decision making process, and that they should be able to guide the support given by the tool. When their level of understanding of the tool is insufficient, they cannot adequately control the tool and a proper interaction between human and tool will become impossible.

Furthermore, the level of insight of the planner into the dynamics of planning situations is important. While facts may lead to insight, for those types of tool output which are not strictly facts simply outputting a number is not good enough when it comes to creating planner insight. This lesson is well-understood by some in the simulation community, who have made a distinction between black-box and white-box models (Barlas, 1996).

Having an insightful planner is useful on not only an operational level, but also from a process development perspective. When planners have an insight into the situation, into assessments of these and future situations, and into the information that these assessments are or are not based on, they can make a more active contribution in improving planning. This can be done in two ways.

The first is by improving on the assessment of situations based on the information they have. Improvements are often the result of changed processes rather than fancy tools. The second is about insight into the way that various kinds of information lead to planning decisions, and how these decisions in turn influence performance for terminals and their customers. This insight may also effect more insight into the ways information they do not have would influence planning, and therefore performance. In short, an information need may be the result of improved understanding. By getting a better grip on the value of missing information, there will be a bigger chance for a push in collecting this information, whether it comes from within the terminal or from other actors in the supply chain.

6.1.2 The planner as the director of the decision process: enable planner control

Explanation: The way in which the tool comes to its output should be controllable by the planner. *Source:* Section 5.2

Rationale: If the tool enforces a problem structure onto the planner that does not match the planner's problem structure, this will hinder acceptance of the tool and eventually it will not be used. This is possible when the planner has different information available than the tool, or when the planner reflects differently upon the same information. As discussed above, one way to solve this is by ensuring that the planner is able to understand how the tool comes to its output and therefore enabling him to take into account any differences in his mind. Another way to solve this would be for the planner to control the problem structure used in the tool, altering it when the planner feels it is necessary.

An example of how this can be used is the calculation of crane productivity. As discussed in chapter 3, a great number of factors contribute to this crane productivity. If the tool takes into account driving distances, and the average productivity on that service, this may usually be enough. Weather influences are ignored in this case. In some situations this factor may be important, in others not. When the planner understands

how the tool calculates the productivity, and agrees, all is fine. However, in exceptional situations where wind would play a larger role than usual, the planner should be able to sidestep the calculation in one way or another, at some abstraction level, to make sure that the influence of the weather as estimated by the planner is taken into account.

6.1.3 Prevent information overload: planner-controlled information filtering

Explanation: The planner should be able to control which information he is exposed to, and which information is condensed or filtered out.

Source: Section 5.3

Rationale: As discussed in section 5.3, having a tool decide on whether information is relevant or irrelevant given a situation has proven to be very problematic. Leaving the planner exposed to all available information at the same time is equally problematic: it will be difficult to maintain an overview of the information and even more difficult to identify and examine critical details. Therefore, the only viable solution is to build a system where the planner can control which information he is exposed to. Earlier research in visualization as discussed in section 5.4 proposes systems that offer overviews of all available information, and then let the user filter and zoom on-demand.

Additionally, one of the main tasks of a planner is to communicate with a great number of people. When the planning tool becomes the place where plans are made and kept, it will also become natural to communicate from the tool to other people. These people may each have different information needs. For example, the information needs can be different when communicating the berth plan to yard planners, gang foremen, tugboat pilots and their agents or lashing crews. To tool should also be able to get the right information to the right people, at the right abstraction level.

6.2 Provide an architecture that facilitates different forms of the planning task

: When designing an application architecture for a berth planning tool, make sure that it is flexible enough to accept differences in problem structure, goals and input information.

Source: Section 3.2

Rationale: When taking the user tasks into account during the design of a berth planning tool, there will be significantly different forms of the planning task. As discussed in chapter 3, the task can exhibit differences between different terminals, between different long-term periods, and between several planning items in a short-term planning span. This poses challenges to tool design, but even more so to tool maintenance and functionality updates. By keeping this in mind in deciding on a tool architecture, these challenges may be minimized. One way to do this would be to create a framework system that can be adapted. This leads to the actual implementation-level design of such a system being a challenge of defining information interfaces: how can the information concepts used for berth planning be defined in a modular way?

6.3 Enable the handling of information with varying levels of information quality

Explanation: Information used in berth planning may have deficiencies on one or more Information Quality dimensions. The tool should be able to handle this information, even when it is incomplete, ambiguous, or inaccurate.

Source: Section 4.4.2

Rationale: This principle is synthesized from literature on Information Quality (IQ) and uncertainty, and from observations on terminals. As discussed in section 4.4.2, literature describes several dimensions of information quality. The observations made on terminals showed that the information used during berth planning indeed can be rated on different levels for various dimensions of IQ that are listed in literature. Some important examples include inaccurate information on arrival and handling times, incomplete information about (future) container locations, and inconsistent information about call sizes.

These IQ levels are very dependent on time: as the time left until the start of operations decreases, the accuracy, completeness and relevancy of information will increase. As discussed in section 4.4.2, literature describes how uncertainty can be viewed as a lack of information. When we associate having a sub-perfect level of IQ for one or more of the dimensions discussed above with having a "lack" of information, we can therefore associate it with experiencing uncertainty. As discussed in section 4.4.2, ignoring this uncertainty or waiting until it is reduced are strategies for dealing with it, but they may not necessarily be the best strategies. As discussed in section 2.6, good berth planning decisions require the planner to look ahead. Berth planners were also observed to make trade offs in these IQ dimensions and employ strategies for dealing with the resulting uncertainties. As a result, planning involves dealing with information that is subperfect on one or more of the IQ dimensions listed above. A tool that is incapable of providing support when information is lacking on these IQ dimensions will be severely limited in its usefulness.

6.3.1 Enable the concurrent consideration of multiple scenarios and alternatives

Explanation: Given the alternatives provided by choice and the multiple possible futures that may emerge from uncertain situations, the planner should be able to consider these multiple scenarios. *Source:* Section 4.4.2

Rationale: There is uncertainty at terminals, but waiting until the uncertainty reduces leaves out very valuable opportunities for decisions. While existing software dealing with uncertainty often focuses on probability calculations, in this case again the idea should be that the planner is in control of which options are considered and in what way.

To enable decision making at an early stage, a way around the uncertainty is to consider multiple scenarios and decision alternatives. This requires thinking in terms of consequences of decisions, risks and opportunities, scenarios and contingencies. In a what-if analysis of sorts, the various alternatives may be evaluated.

6.4 Enable decision support in all plan design stages

Explanation: As discussed in section 4.4, a number of stages precede making a decision (Simon et al., 1986): setting an agenda by choosing issues that require attention, setting goals, finding or designing suitable courses of action, and evaluating and choosing among alternative actions. According to Simon et al., the first three of these stages are usually called problem solving; the latter are called decision making. The overarching activity is called design. A berth planning tool should aim to assist in all these stages.

Source: Section 4.4

Rationale: In berth planning, the point of departure is a pro forma berth plan. An agenda can then be set by identifying points where the actual plan needs to deviate from the pro forma. This is easy in some cases, but can be much harder in others. When a vessel's arrival time is changed, it is obvious that rescheduling is necessary. However, recognizing when savings can be made by designing a "smarter" plan is much harder. One can argue that the entire plan is always the agenda. However, observations at the terminal show that berth planning is regarded as a "puzzle" where planners search for better places to put the pieces. Not every piece of the puzzle gets the same amount of attention however. One could therefore also argue that there must be some mechanism that makes a planner decide to start looking for a place for a specific piece of the puzzle, and that this triggering might even encapsulate much of the design activity itself. Either way, it is possible to offer decision support by providing cues on whether a specific piece deserves attention or not.

In traditional OR approaches, alternatives are matched upfront with a single or compounded goal function. In practice, the definition of goals used by planners may be not be as rigid and it may be dynamic. The planner serves not only as a puzzle solver, he is also the intermediary between the terminal and its customers and even between the terminal and its customers' customers. As a result, the goals that are set often depend on the specific relation with his customers' agent. According to Hofstede et al. (1995), for planners in general these relations may often lead to the planner keeping a balance of favors with several of the other actors. At terminals, a liner agent may for example call in a favor when a specific vessel is delayed but needs to catch up, or when it has a certain deadline for a maritime passageway, when there is upcoming bad weather they'd like to evade, etc. In turn, the planner may call in favors from the agent when a vessel may be handled a bit slower than usual. Depending on these relationships, goals may change due to very specific circumstances.

Designing suitable courses of action and evaluating them was discussed as well in appendix A. Based on this discussion, it was argued that a container terminal planning decision support system can aid in the decision making process in a number of ways: by assisting in the definition of the problem structure, in the representation of this structure, by guiding the generation of alternatives, and in the evaluation of these alternatives. Decision support should aim to contribute in all of these phases. In other words, the tool should assist in deciding what information to take into account during planning, in showing all this information, in working with this information to come up with plan alternatives, and in evaluating alternatives.

6.4.1 Link information to goals and the extent to which they are met

Explanation: Information must be placed in a context that relates to goal attainment. *Source:* Section 4.4.1

Rationale: As discussed in section 4.4.1, literature describes Situation Awareness as being made up of three levels: perception, interpretation and projection. It is projection that ultimately provides the highest level of SA. Endsley et al. (2003) stress the need for providing SA support up to this level. Users need to recognize elements in their situational environment, understand how these elements relate to their goals and project how these elements will influence whether or not they in fact meet these goals. Similar requirements were echoed during terminal visits; one respondent stressed the importance for planners to be able to "think in terms of consequences".

It is therefore not enough to simply "provide information to the planner". The tool should assist in linking this information to goals and in linking it to the attainment of these goals, even when there are multiple goals at the same time. This relates back to Simon's activities; linking information to goal attainment can assist in setting an agenda, in generating alternatives and in evaluating alternatives.

6.5 Enable decision support that acknowledges the existence of other interrelated planning decisions

Explanation: Berth planning is only part of the planning process at an entire terminal, and even across the entire supply chain. This must be taken into account during tool design. *Source:* Section 3.4.3

Rationale: As discussed in section 2.6, berth planning is part of an interrelated set of planning decisions. The performance yielded by a specific plan may well depend on other planning decisions, most importantly discharge planning and yard planning. A decision to housekeep containers for one vessel, but not another vessel may well affect the evaluation of the alternatives. Equipment must be available, labor must be available - in some cases even external labor. Decisions may have to be communicated with lashing and tugging service providers. In some cases, simply providing a copy of the plan will be enough. In other cases, most importantly when aligning decisions with the yard planning, it may be necessary to communicate the plan to more detail and even to communicate the way of thinking that caused the plan to be selected in the first case. When a tool can assist in these communication steps, it can increase the quality of the plans or their execution.

Design Principles: Round-up

This chapter documented various design principles. Their aims are to structure the analysis of the previous chapter, and to guide the design of an actual prototype implementation without specifying a concrete set of requirements just yet. Additionally, their focus should not be on explicit solutions to problems: they should not constrain future creativity. They should be general in nature: while there may be all kinds of differences between terminals that might have to be taken into account in full systems, these principles should hold for all terminals. As such they can be seen as strategical design choices, where the choices made in designing the actual prototype are more on a tactical level.

As such, these principles are used in the design of the prototype in the next chapter. Much like the design principles are linked to the analysis from which they are borne, the specific functionalities implemented in the prototype will be linked back to these principles. Furthermore, as the prototype is just a first iteration, it is just one possible implementation of these principles, where others are available. This will be discussed in more detail in chapter 7.

Give us the tools, and we will finish the job!

Chapter 7

BBC Audio Broadcast, February 1941 SIR WINSTON CHURCHILL

Prototype Design: Embodying the design principles

The previous chapter dealt with a set of design principles, giving direction to the design of a container terminal planning tool. As part of the thesis project, a prototype for such a tool was designed and implemented. This chapter describes that prototype. First, section 7.1 will discuss the nature of prototyping as a software design method and the motivation for using it here. Section 7.2 discusses the functionalities implemented in the prototype and how they relate to berth planning tasks and to the design principles of chapter 6. Section 7.3 discusses the actual implementation, and shows how the functionalities are implemented in the prototype.

7.1 Prototyping: method and motivations

Building full systems from scratch is in many cases a daunting and expensive undertaking. It is often difficult to get it right the first time, and it is hard to communicate about systems that are not there yet. For these reasons, it is common practice to build prototypes of the full system in many fields of design, from architecture to automotive design and from painting to programming. A prototype is "a first-cut approximation of what a new system might be." (Sage and Armstrong, 2000, page 90) and is often built for the purposes of getting a better understanding of user requirements and for demonstration purposes in the form of a showcase for a full system (Sage and Armstrong, 2000; McConnell, 1996).

Prototypes are rudimentary models of a full system. The ways in which these prototypes differ from the full systems varies between various definitions and descriptions of prototypes. The level of detail and scope of a prototype compared to the full system can vary. For some purposes it may be necessary to offer a realistic view of the final system, while in other cases the full system may look completely different from the prototype. One important notion in software prototyping that applies to this project is that prototypes can offer a sense of user experience: "Prototypes can be built and potential users can experiment with them through simulation." (Sage and Armstrong, 2000, page 90) As experimentation and interactivity was a key issue in the design principles discussed in chapter 6, the simulation of this interactivity is also a key issue in the prototype.

Prototyping as a means of fostering development

In some cases "a 'final' system can be developed only through an adaptive process of learning and evolution" (Keen, 1980, page 1). Keen (1980) argues that such cases present themselves when the designer or users are unable to provide functional requirements. This can be because tasks that are to be supported by such a system are only semi-structured and knowledge of them is lacking, because the users do not know what they want, because the task or decision situation will be shaped by the system, or because users show a variety of ways to handle their task to such an extent that personalized use of the system becomes necessary.

These points apply to berth planning. While the goals and technicalities have been reasonably well described in literature, the manner in which planners actually perform their task is not. There are large differences between terminals, differences at the same terminal over time, as well as differences between users within a terminal. Therefore, a development process where requirements for a berth planning tool are to be laid out before development starts will likely run into problems.

In some cases, including this one, the development of a new system requires knowledge about the targeted users, their tasks and their environments. To get this knowledge, access to these users is therefore required to produce a good system. Getting this access as an outsider is usually not a trivial issue. Organizations are often not willing to simply disclose the information, and the burden that this access may put on their employees is not something they would consider as long as they do not see some value for them in the entire process. Outsider development of such systems faces a catch-22: access is prohibited in a development stage that lacks a working system, but lacking access prohibits development of the system.

Keen (1981) discusses how a prototype can be a way out of this paradox by building a 'Version 0' of such a system that is small enough to write off the costs as simple research costs, while having those features that can contribute to better gauging the value of the full system. The full system can then be built up adaptively, by building new features that are estimated to provide more value than they cost.

For these reasons, the goals of this prototype are to showcase what a mature version of the application might look like in order to foster further development by playing a crucial role in getting new ideas, access and funding.

Prototyping as an implementation and evaluation of design principles

The previous chapter offered a set of design principles for a berth planning tool. As discussed in chapter 6, their aim is to give direction to the implementation of functionalities rather than restricting it. Therefore, the implementation of the design as discussed in this chapter is just one of many different possible implementations that would adhere to the design principles. While some definitions of a prototype focus on its purpose or function, Glegg (1981, page 89) thinks of a prototype as "the first embodiment of an idea". Alternative or subsequent design cycles may implement the principles in a different way, with a different or more refined set of functionalities. The goal of this first design cycle is to test the main ideas behind the current design of the tool by showing what an implementation might look like and testing how it performs. This will be discussed in more detail in chapter 8.

7.2 Functionality selection

As discussed in above, the goal of the prototype was to provide a means of evaluating the principles discussed in chapter 6 by serving as a first embodiment of these principles. Furthermore, the prototype can serve as a means of getting more resources to foster further development. Prototyping can be done in a horizontal or vertical fashion. Horizontal prototypes provide a wide range of functions but with little detail. Vertical prototypes provide a lot of detail for only a few functions (Sharp et al., 2007).

On one hand, the goal of the prototype was to offer a working example of what a full system might be. It was therefore possible to make a selection in functionality on the tasks being executed while performing berth planning. On the other hand, the goal was to embody the design principles. As such, it was also possible to make a selection on the design principles being embodied in the prototype by functionality appropriate to each principle. In this research project, several constraints were in place during the development of the prototype. As a consequence, both horizontal and vertical selection was applied.

First, the time to build a prototype was limited; development of the prototype started rather late in the project due to the lengthy analysis phase. Secondly, even at the start of the development period it was unclear what exactly would be the requirements for the system and where it was headed: development of the prototype occurred in an evolutionary fashion. Finally, there was only limited access to real-life systems. As TBA is a company that focuses for a great part on container terminal simulations, the decision was made to build the prototype based on data that was available from one of these simulations. As this data does not span every aspect relevant to berth planning, the task-based functionality was in part influenced by the availability of the data in the simulation data set.

Prototype scope

Prototype development is generally considered to be possible in two fashions: throwaway development, where the prototype will be discarded at the end of the prototyping period, and evolutionary development, where it is assumed that the prototype will evolve into the final system (Sharp et al., 2007). At the start of the prototype development period, throwaway development was chosen as the modus operandi. Little attention was paid to architectural issues and code quality, as the research project was not a programming project. Instead, the focus was on how to visualize the terminal and handling interactivity in dealing with information. However, during the course of the project, much more was built than originally anticipated. As the stability of the prototype was adequate, the project took on a more evolutionary nature. Many features designed for the prototype will now live on through a full version at least in their form, and quite possibly in their source code as well.

Task-related functionality

Table 7.1 lists the task-related functionality implemented in the prototype. As was discussed in chapter 3, planning depends on all kinds of information. One of the main difficulties in berth planning is about getting the vessels close to the containers. In other words, it is about the alignment between berth and yard. As discussed in chapter 1, TBA was interested in applying visualization techniques in this project. The main focus in determining a task-based functionality selection is therefore on the overlap between yard-berth alignment and visualization techniques.

Some of the tasks are analytical in nature and difficult; this includes the estimation of discharge locations and housekeeping possibilities, as well as the estimation of handling time and block congestion. For these tasks, additional vertical selection was applied. A visualization of the current state of the yard and of the load moves driving distances offers task support at least in part, and serves as a showcase of the possibilities for the full system.

Tasks	Imp	lemented functionalities
Inspect upcoming vessel calls	А	Visualization of the vessels scheduled to visit the terminal and their relevant characteristics, such as arrival times, call sizes, vessel lengths and SLA's
Explore discharge possibilities Explore housekeeping possibilities	В	Visualization of the current state of the yard in terms of us- age and free spaces
Estimate yard impact Estimate vessel handling time Estimate block congestion	С	Visualization of the location of load containers for a specific vessel call and corresponding driving distances
Schedule vessel calls	D	Editable berth plan in terms of arrival times, waiting times and berth location
Allocate cranes	E	Editable allocation of a number of cranes to each vessel for a shift or a number of shifts

Table 7.1: Overview of task-related functionality selection

Principle-related functionality

Table 7.2 lists the principle-related functionality implemented in the prototype. Again, horizontal and vertical selection was applied: some principles are left out completely, and others are in it but have a rather simplified functional implementation. Again, the selection was based in part on the alignment with TBA's goal of working with visualization techniques.

Functionalities F, G and H are implemented by the very nature of the tool: its main workflow is based on interactive planning. The planner can edit a plan and can then immediately get visual feedback. Functionalities I and J relate to the manner in which the planner can exercise control over the information on which the plan is based. The tool supports multiple scenarios. Undo and redo functionality provides additional support by making it easy to roll back actions; even toggling back and forth with ctrl-y and ctrl-z can be seen as a mini-scenario of sorts. Functionalities K through N are about the feedback that users get when they change the plan and how this relates to their goals. Again, this can be expanded by providing more detailed feedback or taking more information into account. Functionalities O through S deal with the filtering of information; in many ways, this could be enhanced. For now it gives a good indication of how the principle can be implemented.

The main weakness of the prototype is due the limits in functionality: it's lacking much information, mostly on discharging locations. Taking this into account requires information on yard allocations and upcoming moves, which can be quite complex. When it comes to load container locations, it is also possible that many containers still have to arrive at the terminal. An example of how to deal with this missing information is by giving information on what amount of data the tool feedback is based on. More functions in the same vein are still possible, but again this should give a good indication of how the principle can be implemented.

Principles]	Implemented functionalities
Enable decision support in all plan design activities Exploit the way in which human and computer can add to each others' capabilities		F Interactive planningG Plan problem cuesH Plan rating
Enable the handling of information with varying levels of information quality Enable the concurrent consideration of multiple scenarios and alternatives	}	I Scenarios J Undo and Redo
Provide perception, interpretation and projection support		 K Vessel box heights change when a vessel is dragged to another berth L Berthing zone conflicts are marked red M A shift row turns red when too many cranes are allocated N A vessel is marked red when its SLA's are not met
Leave the planner in control of which information he is exposed to, and by which amount if applicable		 Vessel selection Timeframe selection Remove waiting times and crane allocation and advised berth boxs, but show onHover OnHover vessel and stack info display Control of driving distance lines display
Enable easy comparison of various types of information required for one task	}	T Vessel and stack info display all at same location
Ensure user insight into the capabilities and limiations of the tool	} '	U Data completeness indicator

Table 7.2: Overview of principle-related functionality selection

7.3 Berth planning prototype: implementing the design principles

This section discusses the implementation of the functionalities listed in section 7.2. It will first clarify the technical scope and effort of the prototype, then give some short clarification on the origin of the data used to design the tool, and finally list all the functionalities of the prototype.

7.3.1 Prototype design: technical scope

The tool designed for this project is a fully functional application. It was designed from scratch. As was noted earlier, the main focus was on providing a visual interface to control the plan and to convey planning information. The Java programming language was selected as the tool of choice, as Java provides abilities to design such a visual interface, and this language was most familiar.

The result is a design of almost 50 classes and near 10,000 lines of code, all designed specifically for this



Figure 7.1: The layout of the yard

project. Relatively few external libraries or code snippets were used. More so because the design process was rather evolutionary, maintaining the ever-expanding code base took quite some effort. Redesign of the tool is likely to yield a more compact and more easily maintainable code base. Still, the resulting prototype proved to be functional and relatively stable; this will be discussed in more detail in chapter 8.

As the code base grew evolutionary - and in fact for a much longer period of time than originally intended - there is no thought out architecture implemented. At the end of the project, the code base would require a redesign in order to arrive at a sensible architecture. Documenting the technical scope by means of class diagrams would therefore not provide any insight at this stage. In order to provide at least a minimal documentation of the technical scope, a list of the designed classes and their code length is provided in appendix C.

7.3.2 Prototype design: case selection and data sources

The prototype is based on data from a TBA simulation of an actual terminal. The terminal is a straddle carrier terminal. Containers are stacked 2-high at most. It features an empty yard on-site called the "Pota-Park", with a buffer stack at the quay. Reach stackers move MTs between the PotaPark and the MT buffer. The terminal features eight Post-Panamax quay cranes, all operating a single hoist: no twin carry or tandem carry moves are made. The terminal has been running at almost peak capacity for quite some time, with the yard fill rate at about 85%. The draft at the left side of the quay is too small for deep-sea vessels to berth. At the right side of the quay, where the PotaPark buffer stack is, the QC rails end. Therefore, vessels cannot berth there either. All this is displayed in fig. 7.1. Chapter 8 will discuss the scenario used and its validity in more detail. The following sections will discuss the functionality implemented in the prototype. There are three main panels in the prototype: a berth planning panel, a yard layout panel and a driving distances panel. A fourth has been designed but has been removed from the prototype. It will nonetheless be discussed as well.





7.3.3 Berth plan panel

Figure 7.2 shows the berth plan panel; the functionality implemented in this panel is shown in table 7.3.

Table 7.3: Overview of functionalities implemented in the berth plan panel

Implei	Implemented functionality		
A	Visualization of the vessels scheduled to visit the terminal and their relevant characteristics, such as arrival times, call sizes, vessel lengths and SLA's		
D	Editable berth plan in terms of arrival times, waiting times and berth location		
E	Editable allocation of a number of cranes to each vessel for a shift		
F	Interactive planning		
G	Plan problem cues		
Н	Plan rating		
Ι	Scenarios		
J	Undo and Redo		
Κ	Vessel box heights change when a vessel is dragged to another berth		
L	Berthing zone conflicts are marked red		
М	A shift row turns red when too many cranes are allocated		
Ν	A vessel is marked red when its SLA's are not met		
0	Vessel selection		
Q	Remove waiting times and crane allocation and advised berth boxes, but show on Hover		
R	OnHover vessel and stack info display		
Т	Vessel and stack info display all at same location		
U	Data completeness indicator		

The berth plan panel is the main planning panel of the tool. It shows a berth plan in a way that is typical for many terminals: the quay is represented on the horizontal axis, and time on the vertical axis with time moving ahead downwards. The panel is filled with rectangles representing vessel calls; their widths define the vessels' widths, their heights define the vessels' handling times.

The main goal of the berth plan panel is to provide the planner with a means of interactively designing a berth plan. The idea is that the user should be provided with an intuitive means of editing a berth plan design, and is immediately presented with feedback on this design by the tool in a number of ways, that will be described below.

Berth allocation and distance-related productivity estimation

One of the most important variables in a berth plan design is the berthing location of vessels. In the berth plan panel, this variable can be controlled by simply dragging a vessel from one location to another. In fig. 7.2 the mouse is hovering over the *UASC Samarra*. As a result, the line color of its rectangle changes from black to orange, thereby highlighting the vessel. Now, the mouse can be dragged to another location to move the vessel's berth location. To indicate this possibility, the mouse cursor changes to a *move* cursor.

The tool is equipped with a simple model that calculates an average crane productivity based on the location in the yard of the export containers that have to be loaded on a vessel. As containers arrive onto the yard through the gate or by other vessels and will then be assigned a location, a location is not known upfront for every export container. To indicate the completeness of the data that the advice is based on,



Figure 7.3: Allocating a berth to a vessel in the berth plan panel

the percentage of the call size with a known location is shown in the vessel info display.

Based on this model, the tool calculates a recommended berthing position for each vessel. This recommended position can be shown in the berth plan and is linked with the corresponding vessel. The steepness of the line provides a cue as to the suitability of the chosen berth. Additionally, it can calculate a prediction of the handling time for each vessel based on this average crane productivity. When dragging a vessel to a berth that is closer to the recommended position, the height of the vessel's box will decrease as the vessel is dragged. This is shown in fig. 7.3.

In addition to being able to change the berth location, the arrival time and waiting time of a vessel can also be changed. When the *shift* key is pressed on the keyboard, the vessel can be dragged vertically to alter the arrival time. To assign a waiting time for the vessel, the block can be dragged downwards when *ctrl* is pressed. The waiting time is visualized unobtrusively with a gray rectangle, but when a vessel is highlighted the box will turn orange and show the waiting time in hours (fig. 7.5). Additionally, hovering over a box will make the program display some more details for that vessel on the left of the panel.



Figure 7.4: Allocating cranes to a vessel in the berth plan panel

Crane allocation

The berth plan can also show the number of cranes allocated to each vessel. An orange line drawn in the vessel's box denotes the number of cranes allocated. Additionally, crane icons are drawn in one of the shifts where cranes are allocated for that vessel. Of all the shifts in which cranes are allocated, the tool picks the most suitable one; it prefers the shifts with the maximum number of cranes, but tries to draw the icons in the middle of the box as much as possible to prevent it from being drawn over the vessel name or cost report. To change the number of cranes, one simply moves the mouse over the orange line (fig. 7.4). The mouse will change to a *horizontal resize* cursor. When the mouse is pressed on the line, the box will be cleared of any other info and the crane icons will be drawn in the shift where the orange line is pressed. When dragging the mouse, the crane icons will be added or removed as indicated. The maximum number of cranes that can be assigned to a vessel is dependent on its size; the line can not be dragged beyond this point. When the line is dragged towards zero, it will respect this but allocate one crane to the next shift instead.

The shifts affected by dragging the line can be controlled by the planner. By default, the shift where the line is pressed and all subsequent shifts are affected. By pressing *shift* a single shift can be edited. By pressing *ctrl*, all shifts are edited. The shifts that are affected are visualized with a red line (fig. 7.4).

On the right of the panel, a small box that displays the number of cranes allocated is shown for each shift. This terminal is equipped with eight cranes. When there are more than 8 cranes allocated in a shift, this constraint is violated. The line color of the box will change to red, and the entire row will get a red background (fig. 7.4).

Contracts, penalties and plan rating

The prototype implementation of the tool features a very simple contract model. It has three types of service models: large vessels, medium vessels, and feeders. For each service, different berth productivities are contracted to the customers. Depending on the usual call size for the service and whether a vessel call is in the agreed window or not, a penalty may be incurred when the vessel has to wait too long for berthing or when it is handled too slowly. When there are penalties, the name of the vessel will be drawn in red instead of black letters. The calculated penalty is shown. Additionally, the projected handling costs will be calculated and shown. This gives the planner a sense of the quality of the plan, or at least a basis for comparison between alternatives.



Figure 7.5: Hovering over a vessel box in the berth plan panel

Information display filtering

Especially for a large terminal, the entire display may become overwhelming. This will be even more true when additional overlays are added in the future. The user can therefore choose to turn off the display or crane allocation, berthing suggestions or waiting times. Additionally, certain vessels may be removed from the display if the planner chooses so. In fig. 7.5, all these displays are turned off. However, the mouse is hovering over the *MSC Tomoko*. As discussed earlier, hovering a vessel will bring up more information for that vessel. It will also make the tool draw the waiting time and berth advice even when they are filtered out for other vessels. The vessel detail field on the left is drawn at the same position for all vessels. When comparing call size between two vessels for example, the planner can fix his eyes on the info field as he moves the mouse from one vessel to another.



Figure 7.6: The scenario manager

Scenarios, editing control and comparison of alternatives

As stated earlier, the goal of the berth plan panel - in fact, of the whole tool - is to facilitate interactive planning and exploring alternatives. In order to facilitate the creation and comparison of multiple alternatives, a scenario manager was implemented. This scenario manager can be seen as a sandbox of sorts. It enables the planner to work in multiple threads. New threads are created by copying existing threads. The current thread (called a *scenario*) is highlighted by enlarging it and coloring the scenario header (fig. 7.6). To compare it with another scenario, that scenario can simply be clicked to restore it to the planning panel.

When editing the plan in the berth plan panel, the thumbnail for the current scenario changes along. When a planner is satisfied with a scenario, he can set it as the current plan. That plan is shown on the left of the scenario bar, and is not editable. While editing a plan, a planner can use *ctrl-z* and *ctrl-y* to undo and redo changes. Each scenario keeps track of its edits; when switching to another scenario, the actions taken in that thread can be undone and redone even when scenarios are switched in the mean time.



Figure 7.7: The yard layout panel

86
7.3.4 Yard layout panel

Figure 7.7 shows the yard layout panel; the functionality implemented in this panel is shown in table 7.4.

Table 7.4: Overview of functionalities implemented in the yard layout panel

Implemented functionality				
В	Visualization of the current state of the yard in terms of usage and free spaces			
R	OnHover vessel and stack info display			
Т	Vessel and stack info display all at the same location			

This panel is a display of the current state of the yard. It shows a satellite map of the terminal in the background. The background is darkened in order to emphasize the data rather than the picture of the terminal. Drawn upon it are the various container stack blocks and their status. A blue bar represents a free slot, a dark yellow bar a slot with one container on it, and a bright yellow bar represents two containers stacked on that position. This terminal in particular has 18 regular stack blocks, a small number of reefer blocks and an empty stack on the right of the quay.

As shown in the figure, when hovering the mouse over a particular stack block, some relevant data is shown on the screen about that block. This includes the name of the block, the total capacity in TEU, fill rate statistics and the number of empty rows. At some straddle carrier terminals, the grounding strategy favors containers that have to be loaded onto the same bay of the vessel to be placed in the same row at the container yard. For this reason, it can be useful to know how many free rows there are in a stack block.



Figure 7.8: The driving distances panel

100

7.3.5 Driving distances panel

Figure 7.8 shows the driving distances for load containers; the functionality implemented in this panel is shown in table 7.5.

Table 7.5: Overview of functionalities implemented in the driving distances panel

Implemented functionality				
A	Visualization of the vessels scheduled to visit the terminal and their relevant characteristics, such as arrival times, call sizes, vessel lengths and SLA's			
В	Visualization of the current state of the yard in terms of usage and free spaces			
С	Visualization of the location of load containers for a specific vessel call and corresponding driving distances			
F	Interactive planning			
Ι	Scenarios			
0	Vessel selection			
Р	Timeframe selection			
R	OnHover vessel and stack info display			
S	Control of driving distance lines display			
Т	Vessel and stack info display all at the same location			
U	Data completeness indicator			

This panel's goal is to let the planner explore where moves will occur, based on the current plan, in order to estimate driving distances. It shows the same map of the terminal as is shown in the yard layout panel, but this time the container stacks are not drawn. Instead, this panel visualizes load moves that need to occur for a selectable set of vessels over a selectable time span.



102

The timeslider: time span control

The time slider (fig. 7.9) is a component originally designed by Chin (2007) and was adapted for this prototype. It functions as a time interval selector, in this case for the moves that are visualized in the driving distances panel. It features three handles. The start of the selected time span can be controlled with the left handle, the end of the time span with the right handle. The middle handle simply moves the time span while keeping the length of the time span constant. The planner can control the length of the selectable time range using the spinner controls on the left and right, by clicking the spinners' up and down arrows or by inputting a date in the text field. Clicking the left and right arrows will make the selected time span exactly one shift in length, and then move it one shift right or left accordingly. In the vessel selection box at the top left of fig. 7.9, the vessels that fall within the selected time frame are colored green. The implementation of the timeslider is discussed in more detail in appendix B.2.

Container move visualization

The vessels that are selected and that are in the selected time span are shown at the quay in fig. 7.8. Again, a green "shadow" vessel is shown to indicate the advised berth if that option is selected. Based on the load sequence that is entered into the tool, it will estimate a move time for each container. If the move time is in the selected time span, it will be visualized with a yellow line from the location of the container in the yard to the vessel on which it will be loaded. The affected stack blocks are shown with a yellow rectangle, and the number of containers that will be moved from that block are displayed in the rectangle.

By simply clicking the control on the top left of the panel or even somewhere else on the panel, the unit of the move count can be switched from boxes to TEU. By clicking the *Show Block Outlines* control on the top left of the panel, the block outlines and move counts will be removed or re-added to the display. The *ctrl*-key works as a press-and release control performing this function. By hovering the mouse over a vessel, only the moves belonging to that vessel will be visualized and counted.

Color design

The color of the lines was changed during tool design. At first, load moves were visualized with red lines and discharge moves with blue lines. Discharge moves are now not present in the tool, and load moves are now visualized with yellow lines as some people may have trouble seeing red lines. Still, color is a problematic issue that requires more attention. For example, while the image of the terminal map was darkened in a dark blueish shade to remove attention from it, outside users found the color to be obnoxious.



Figure 7.10: The heatmap panel

7.3.6 Heatmap panel

Figure 7.10 shows the heatmap panel; the functionality implemented in this panel is shown in table 7.6. It is based on code by Johan Liesen¹.

Table 7.6: Overview of functionalities implemented in the heatmap pa	nel
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Implei	nented functionality
С	Visualization of the location of load containers for a specific vessel call and corresponding driving
	distances
F	Interactive planning
G	Plan problem cues
Ι	Scenarios
P	Timeframe selection

This panel's goal is to let the planner explore where moves will occur, based on the current plan, in order to estimate yard congestion. It shows a heatmap visualization of moves that occur within the time frame selected in the timeslider. There can be situations on terminals where the number of moves that need to occur in an area in a certain time frame are too much to handle; congestion will be the result. In terminals that use yard crane, a whole block will be congested. In a straddle carrier terminal, the block congestion will be less as multiple SCs can work in the same block. However, there will be congestion when a number of SCs need to work in the same row or neighboring rows.

The intended goal was to calibrate the heatmap in such a way, that the cues given by the heatmap in the form of intensely lit areas would correspond to those situations where congestion would occur. Meeting this goal proved problematic, as there was no data to support the calibration. Furthermore, to make this functionality useful for planning would require planners to be able to forecast time and location for all yard mutations in a given period for all vessel, gate and housekeeping moves. While there could be possibilities to make this work given time and access to a terminal, these tasks are not properly supported by the tool as it is now. Consequently, the heatmap panel was scrapped from the prototype.

7.4 Prototype design: round-up

This chapter discussed the design of the prototype, based on a selection of the design principle-related functionality and a selection of the task-related functionality. It provided some explanation of the technical scope, and an extensive explanation of the various functions of the prototype. In order to test the prototype, a workshop was conducted. This will be discussed in the next chapter.

¹http://www.itstud.chalmers.se/~liesen/heatmap/ - accessed on February 4, 2011

If a picture is worth a thousand words, a prototype is worth a thousand pictures

Chapter 8

Anonymous

Principles & Prototype: An evaluation

This chapter provides an evaluation of the design principles presented in chapter 6 and the prototype presented in chapter 7.

8.1 **Prototype evaluation**

In this section, the evaluation of the prototype will be reviewed. First, the design of the workshop will be discussed. Then, the outcomes of the workshop itself and the questionnaire will be shown. Finally, further remarks collected from workshop participants and from terminal staff during additional visits are discussed.

8.1.1 Workshop design

This section will discuss the design of the workshop: the experimental setup, the scenarios and goal given to participants, and the composition of the participant group.

Experimental setup

The experimental setup for the evaluation consisted of an evaluation workshop, where participants would have to solve a berth planning problem. The original plan for the evaluation was to first have a try-out with a small number of people at TBA, then a larger test with more staff, and finally some tests with terminal planners. However, due to practical limits and scheduling issues, in the end only the try-out and a second workshop with 7 participants from TBA were done. Most of these people work as simulation consultants and perform all kinds of studies on terminals. However, none of these people have extensive experience as a planner. Only one participants has actually worked at a terminal for a significant period of time.

The goals of the workshop are to get some sense of how people interact with the tool, how well they handle a berth planning problem, and how their performance would compare with planning in a more traditional way. Additionally, it makes for a nice opportunity to showcase the prototype. As was discussed in chapter 3, a very typical way of planning is by using Excel. For that reason, in the workshop the use of the tool is compared to using an Excel spreadsheet.

The experimental setup therefore requires a comparison between Excel and the tool. Various options were considered and are shown in fig. 8.1. In the diagram, two scenarios may be used (A and B). T denotes a test using the tool, E a test using Excel. The problem with the first option is that to be able to compare

the results, a homogeneous test group is required. This is hardy feasible, especially given the small number of participants.

Ses Group 1: Group 2: (a) Setup 1		ion 1 "E "T	Group	Sessi Group 1: A, (b) Se 2 Group 1: Group 2:		Sessi B	ion 2 ,T		
Group 1: Group 2:	Session 1 Session A,E B, A,E B, (c) Setup 3		2 C			ion 1 ,E ,E etup 4	Session 2 B,T A,T		
Group 1: Group 2:			Session 1 A,E A,T (e) Setup 5	Session B,T B,E	2				

Figure 8.1: Five alternative experimental setups

The second option is a repeated measures design. The problem here is that learning effects come into play: if the group does better the second time around, it is hard to say whether that is because they have learned more about planning, the terminal or the type of puzzle. The more alike the two scenarios are (with the same scenario being used as an extreme case), the more learning effects will be an issue. The less alike they are, the less the outcomes for each session can be compared.

The third option is a non-equivalent groups quasi-experimental design. This option would compensate for learning effects, but the tool would be used in only one of four sessions. This is socially not very desirable. When both groups do the tool session as shown in the fourth option, the groups can not be compared and learning effects again are an issue.

The fifth option was therefore chosen. In this way, when group one performs better on the second test, again this could be attributed to tool influence or learning effects. However, when group two performs worse on the second test, a stronger indication of tool influence would be measured. Additionally, it requires a relatively similar scenario. For the results of the first group, it is hypothesized that they will perform better in the second session, with the tool. For the second group, it is hypothesized that they will perform better with the tool too, but that the measured difference is smaller due to the learning effect giving them an advantage when planning with Excel.

Additional benefits of this approach is that it will be more fun for the participants compared to some of the other options, and that facilitation is easier when only half of the group is doing the test with the tool at the same time.

The try-out: design parameter combination

Two very important parameters in the workshop are the difficulty and nature of the problem given to the participants, and the amount of time they get to solve it. As this could not be determined beforehand, a try-out workshop was conducted. In the try-out, the scenarios used were found to be adequate. Based on this try-out workshop, participants in the second workshop were given 40 minutes for each scenario.

Workshop scenarios and tasks

Although the simulation differs from reality in some points, the overall situation was relatively realistic. The TBA staff that participated were given a list of the assumptions and limitations. These related to things such as transhipments being absent, discharge boxes being spread out in a similar pattern as the load boxes and therefore having no effect on driving distances, and the assignment of straddle carriers to cranes being fixed. Participants were given a short talk and a document that went through the layout of the terminal, and that discussed the details and parameters step by step. The tool calculated handling costs and penalties based upon the plan, and the participants' goal was to minimize the total costs.

As the focus of the workshop was on how the participants would interact with the tool, the scenarios given to the planners' was in the form of a static puzzle. No new information was introduced during the workshop. Additionally, this would prevent the participants from experiencing a feeling that their assignment was 'unfair'. To give an indication of the nature, comparability and difficulty of the workshop scenarios, the scenarios and their optimal solutions are shown in fig. 8.1. As no optimization module is built into the tool, these optimal solutions are simply the best solutions found so far; for scenario 2, the plan made by one of the participants contained an element that made improvement to the best solution found during the design stage possible.

8.1.2 Workshop results

This section will discuss the workshop results. First, the outcomes of the experiments will be discussed. Then, the results of the questionnaire will be discussed.

Experimental outcomes

In both the try-out and the second workshop, the tool functioned adequately. Although the response from the tool was slow for some participants, no crashes or other events prevented any participants from completing their assignment. For the participants, the experience was a rather pleasant one. Most participants responded enthusiastically, and did their best. The challenge of the puzzle gave them an almost game-like experience.

When it comes to the Excel test, most participants did not have enough time to complete the assignment the way they intended to. The participants in this workshop still showed skill in Excel, handling the data given to them as well as they could. Differences were shown in how they handled their task. For example, the vessel data was given to them in a rather large table. One column had contracted arrival times, and another actual arrival times. As the penalties for some vessels depended on these being the same, these columns had to be compared. While one person was able to very quickly see the differences, another insisted there were none. When informed that there were, it took him only a second of rapid keystrokes to produce another column actually testing the equality of the other two columns.

When time ran out, they were told to finish up and their plan was then input into the tool to calculate the handling costs and penalties. When their plan resulted in berthing clashes that could not be foreseen in Excel, their solution would be adjusted by doing what was deemed to be a logical solution during an actual operation. In other words, any malfunctions in the Excel plans were not unnecessarily aggravated.

The results for each participants on the questionnaire along with their scores on the assignments are listed in table 8.1 and summarized graph-wise in fig. 8.2. While the low sample size would make a statistical analysis superfluous, the following observations were made:

• *Performance using the tool is better than using Excel* When comparing between the groups, on both scenarios the Excel group outperformed the tool group



(f) Scenario 1 - Initial Situation



(g) Scenario 1 - Optimal Solution



(h) Scenario 2 - Initial Situation



(i) Scenario 2 - Optimal Solution

Figure 8.1: Workshop Scenarios

Question	A (Group 1)	B (Group 1)	C (Group 1)	D (Group 1)	E (Group 2)	F (Group 2)	G (Group 2)	Average	T-Test
I felt like I had a good overview of	4	4	4	4	2	2	3	3.3	0.009
the various vessels, berths and assigned cranes	6	4	5	4	5	5	5	4.9	
I felt like I had a good overview of	4	4	2	3	1	2	2	2.6	0.000
the consequences of a choice in berth or crane allocation	6	5	5	5	5	4	5	5.0	
I tried as hard as I could to make a good plan	5	5	5	2	6	4	5	4.6	0.019
	6	5	6	5	6	5	6	5.6	
I enjoyed making the plan	6	4	5	3	4	4	4	4.3	0.001
	6	5	6	5	6	6	6	5.7	
I felt stressed while making the plan	2	1	2	3	4	2	1	2.1	0.017
	1	1	1	2	0	1	0	0.9	
I felt bored while making the plan	0	0	1	2	1	2	0	0.9	0.316
	0	1	1	5	1	0	0	1.1	
I felt the urge to explore alternatives in order to find a good solution	6	3	4	4	5	1	1	3.4	0.023
	6	5	5	5	5	6	5	5.3	
When you tried to look for a good plan, it was easy to find one	3	3	4	2	1	2	3	2.6	0.005
	6	4	4	5	5	4	4	4.6	
The planning process cost a lot of effort	5	1	4	6	5	4	4	4.1	0.002
	0	1	2	2	1	0	2	1.1	
At the end of the session, I felt proud of the plan I had made	3	4	2	1	2	4	3	2.7	0.003
	5	5	4	5	5	4	5	4.7	
I had enough time at my disposal to make a good plan	3	3	0	1	1	0	4	1.7	0.001
	5	5	5	5	4	2	5	4.4	
I had a lot of useful information at my disposal	4	3	4	1	2	4	2	2.9	0.079
	5	5	1	6	5	4	5	4.4	
I spent too much time on irrelevant details instead of the main points	5	1	1	4	4	1	1	2.4	0.325
	1	1	2	1	4	4	1	2.0	
The tool I used in this session is a good tool for berth planning	4	2	2	1	0	2	3	2.0	0.001
			5	5	5	5	5	5.0	
Total Costs Scenario 1	873	845	852	939				877	
					713	832	728	758	
Total Costs Scenario 2					673	621	600	631	
	608	624	568	576				594	
Total Costs Scenario 1	80%	68%	71%	108%				82%	
					13%	63%	20%	32%	
Total Costs Scenario 2					54%	31%	22%	36%	
	25%	32%	7%	11%				19%	

Table 8.1: Workshop Results: by participant

Excel Tool on average. Still, there is some overlap in the second scenario, where one out of the three participants using Excel in the second session outperformed two out of four participants using the tool in the first.

• Performance on Scenario 2 is better than on Scenario 1

In general, performance on the second scenario was better than on the first. This could be attributed to randomness in the data due to the low sample size, to scenario two simply being easier than scenario one in terms of performance (not necessarily in effort), or to learning effects which mostly showed in improved performance on Excel in the second scenario.

• Differences between participants

There are differences between the participants. Even though the participants group was relatively , some simply ran into problems in solving the scenario. One participant managed to make things worse than the initial scenario using Excel; another participant in the first session using the tool had a lot of trouble compared to his peers but recovered in the second session using Excel.

Part of the functionality of the tool for the workshop was a screenshot dump after every plan edit; consequently all alternatives explored by the participant could be tracked. These dumps were investigated to investigate why some participants performed much worse than his peers. For the sessions using the tool, the differences in handling costs can in part be explained by micromanagement of the number of cranes in each shift, and the assignment of waiting time. However, some participants missed opportunities to put vessels closer to the container, for example by switching vessels around or by putting more cranes on an earlier vessel so that the next can use the same berth.

An analysis of the screen dumps showed that these participants got stuck early on in this micromanagement; they were trying to figure out an allocation of cranes to minimize costs at the current vessel position. Most of the participants were not done by the end of the session; it is possible they would have eventually found a better plan. This includes these participants as well. For example, participant F performed rather poorly. While the other two participants in his group discovered that the *Clio* could be put on its ideal berth on the right, this participant never once during the session explored the possibilities for putting the vessel there.

Much like in the account of the freestyle chess tournament in section 5.1, it seems that here a good solution strategy or process is required to achieve good results. For example, by first laying out all vessels at their best berth and then figuring out whether there are any crane assignments possible to remove the berth conflicts, these opportunities might not have been missed. Now, a depth-first search strategy was employed and cut off midway, resulting in a suboptimal solution.





Figure 8.2: Workshop Results: by average

114

Questionnaire results

The goals of the questionnaire were to more formally measure the participants experience during the workshop, and measuring their responses on a number of questions relating to some of the design principles. These are compared between the Excel session and the tool session; the questionnaires for both sessions were identical. Participants were asked to fill out the questionnaire directly after each session; consequently, the first group filled out the Excel questionnaire first, while the second group filled out the tool questionnaire first. Again, the sample size is too low to make any definitive conclusions, but some observations can be made. For the questionnaire, more data is available than just the participant scores and a t-test was run. The significance levels are included in the table; as for all questions a difference in score is expected between Excel and tool, the significance levels are for a one-tailed test. A significance level lower than 0.05 indicates a significant difference between the Excel and the tool responses, while a higher level means that there is no statistically significant difference.

First of all, there was a group of questions relating to the planners' experience. How did they feel while making the plans? Obviously, a lot of feedback was given during the workshop itself and participants were very enthusiastic. The responses to the questionnaire confirm this feedback. For both the Excel session and the tool session, participants gave strong indications of enjoying the experience, and of having a strong motivation to find good plans.

The biggest differences were found in the perceived effort that the planning process took and the availability of time to make a plan. Large differences were also found in the extent to which participants felt proud of the plans they had made, in their perceived urge to explore various alternatives, and in their convictions that a good plan was available when looking for one. Stress and boredom levels were indicated to be low in both sessions. In both sessions, participants indicated they did not have strong feelings of spending too much time on irrelevant details.

The questionnaire also contained questions relating to the design principles. First of all, it can be noted that all participants apart from one felt that with the tool, they had more useful information available to them. As the data given to them was virtually the same, this would suggest that the perceived amount of useful information depends on the way in which the information is presented and the participants' ability to handle the information with the tools they have at their disposal. However, due to one participant indicating he felt he had more useful information with Excel, the t-test yields an insignifanct result.

Furthermore, when asked to indicate the extent to which they felt they had a good overview of elements in the situation such as the various vessels, berths and cranes, the participants gave higher scores after using the tool. The difference became even clearer when asked to indicate the extent to which they felt they had a good overview of the consequences of their actions. Ultimately, when looking at the results for the last question, the participants indicate that they feel that the tool, more than Excel, is a good tool for berth planning.

8.1.3 Other feedback: opinions from workshop participants and terminal staff

This section will discuss other feedback that was received on the tool. Not only did the workshop participants have further comments, some terminal staff also were given a demonstration and had comments available even though they could not free the time to do a workshop.

When it comes to the workshop, one participant of the try-out workshop had noted that the tool gives a false sense of certainty; in reality, there are always risks and uncertainties. The tool does not properly take this into account yet. He argued that in Excel, when making estimates, at least you know those are estimates. Another participant commented that the time limit prevented him from making a good plan by exploring all the alternatives. Finally, one participant commented that it would have been possible to construct a better tool in Excel, even though it would have missed features such as the vessel box autoscaling. In Excel, vessel boxes can be dragged around much in the same way as in the tool. However, the link between information and visual output is much harder to make in Excel; linking the information sources is harder; and finally, calculating over the available information and then presenting this back in an intuitive way is much harder. For many features, it would not be possible to achieve the same in Excel as in the tool.

For the thesis project, one of the terminals that was visited before the design stage again was visited to show the results. They had no time for a full workshop, but some valuable insights were gained from the discussion following the demonstration. One of their main points of critique was that of the mindset when making berth plans. In the tool, the vessel estimated time of departure depends on the productivity and the number of allocated cranes. In practice, the approach is different: the time of departure is fixed, and the plan is made in such a way that this time of departure is satisfied. Furthermore, the presentation of some KPIs could be improved; they would have liked seeing KPIs such as boxes per hour, straddles per box, or euro per box. They also found it hard to see how many cranes were assigned in a certain shift. They suggested showing the cranes in the shift when the mouse is moved over the shift indicator on the right of the screen.

What they did like was the ability to work with different scenarios; although they insisted that they already take many alternatives into account at the planning stage, they appreciate its value as a communication tool, including to external organizations. As this terminal was a single-user terminal, this included the liner. The tool could assist in showing the customer the trade-offs involved with various alternatives. Another point relating to this was the notion of information filtering. Especially when more information gets added to the system, they perceived the ability to 'turn off' certain parts of information as very valuable. They discussed this in terms of printing schedules 'at various levels', where the people involved on various levels would each want to see something in a different way, including yard managers, discharge planners, the liners, lashes and foremen.

8.2 **Prototype evaluation: reconfrontations**

This section will wrap up the evaluation based on the outcomes of the tool design stage and workshop. Basically, the tool can be evaluated on two fronts: on its match with the principles, and on its match with practice.

8.2.1 Reconfronting the principles

This subsection will discuss the relation between the prototype and its evaluation on one hand, and the design principles on the other. For convenience, the design principles are re-listed in table 8.2.

When it comes to the first three of these, the tool supports it on the most fundamental level. It offers support on points where humans are not very strong: maintaining an overview, doing calculations, handling large amounts of data. On the other hand, the planner can still apply all his tacit knowledge, make sure that little details are not missed, or do something else when the tool support hits it limits, all the while being supported by the system. When it comes to transparency, the visualization plays a strong part. Because all driving distances are visualized and because the box dynamically changes, the planner can explore the consequences of location on handling time himself. The limitations of input data was also shown, in the form of an indicator of the percentage of load containers present in the yard. While full on discharge planning is not available for example, the support that the tool does give is the layout of the yard. The transparency of the advice coupled with limited functionality allows the planner to pick up the thread Table 8.2: Overview of Design Principles

6.1:	Exploit the way in which human and computer can add to each others' capabilities
6.1.1:	The planner as the director of the decision process: ensure system transparency
6.1.2:	The planner as the director of the decision process: enable planner control
6.1.3:	Prevent information overload: planner-controlled information filtering
6.2:	Provide an architecture that facilitates different forms of the planning task
6.3:	Enable the handling of information with varying levels of information quality
6.3.1:	Enable the concurrent consideration of multiple scenarios and alternatives
6.4:	Enable decision support in all plan design stages
6.4.1:	Link information to goals and the extent to which they are met
6.5:	Enable decision support that acknowledges the existence of other interrelated planning decisions

where the tool has to leave it, and adjust the plan based on a discharging scenario himself, thus giving him control over the planning process.

The information filtering approach taken here has worked well. All details can be removed, allowing not only the planner to more easily work with the information, it also allows for communication with others without being distracted by irrelevant details. The questionnaire showed that participants had a good overview of the elements in the situation; the filtering of information may have contributed to that.

Principle 6.2 has not been implemented in the prototype. While implementing this in the code requires redesign, on a conceptual level much needs to be researched as well. How to enable planners to switch between different levels of abstraction has not been explored yet and deserves more attention. For examples, when the planner has ideas where containers will be in the yard but no data is available yet, what would be suitable interfaces between the ideas in the planners mind and the concepts in the tool?

Uncertainty is something that has not been taken into account much. As said before, the tool can work with incomplete data, but when it comes to uncertainties the tool offers little support in handling risks in handling time for example. The main support that it does give is that it allows the planner to work with multiple scenarios and compare these. The responses on the questionnaires indicate that the tool indeed gives incentives to do this.

The workshop showed that the strategies are an important element when leaving the human in charge of planning. Not much is known about how actual planners would interact with the tool. To be able to get a grip on these issues, more empirical research and experience is required. This relates to principle section 6.4. The prototype offers support in setting an agenda (cost and constraint violation indicators, berth advice boxes), in exploring alternatives (by allowing the planner to move vessels around) and evaluating them (by listing the costs and penalties), but still the participants did not always manage to find the right plan. Which steps in the problem solving process still require more attention is unclear.

The 'situation awareness principle' has been supported pretty well. In the questionnaires, participants indicated an improved overview of elements and consequences due to the tool. When decisions change, the consequences of the changes are immediately shown. When this has an affect on the goals, it can immediately be identified.

The visual nature of the tool is very important for the last principle. Staff at one of the terminals that was visited has indicated that they see potential in the tool for showing others what alternatives are possible and explaining the consequences. Additionally, the scenario feature can be used to set the various options other planners have, and start exploring berth plan alternatives from there.

8.2.2 Reconfronting practice

Section 3.5 discussed the various opportunities and challenges for berth planning. Overall, when relating the prototype functionalities to these opportunities and challenges, it offers a pretty good start. The nature of the tool will allow planners to work more dynamically and consider alternatives and their merits. The alignment between various plans can be improved due to the visual aspects of the tool that enable more clarity and reasoned discussions between various planners.

The most important 'feature' offered by the tool that will be decisive when considering organizational issues is that it will offer value for the planners at an early stage, when not all functionality has been implemented. As such it can be a gateway tool of sorts by slowly improving and evolving planning practices, data gathering and information systems linking, rather than requiring a one-time complete revolution. This can then go hand in hand with the expansion of tool functionality. As the development of features may require intimate and detailed knowledge on the terminal operations, having access will make this process considerably easier.

Given the current prototype frame of interactive berth planning, other features can be designed. For example, logging features may assist in evaluating decisions. Interactive input of source data, for example on the container yard or vessel schedule, may offer opportunities for designing new pro forma schedules or for practicing future environments. A more active approach to the development of new best practices may be triggered by the tool. However, this change may require quite some time.

As was noted in section 4.3, scheduling support systems are often introduced, and then stop from being used some time later. Having some basic use for the tool for planners that works with their current planning process enables the further development of the tool to sit out the ride.

8.3 Prototype evaluation: round-up

As discussed in this chapter, the prototype has been subjected to an evaluation on its match with the design principles and problem analysis, and to a comparison with a more traditional Excel-based approach in a workshop setting with TBA staff. On a technical level, the prototype performed sufficiently. There were no technical problems during the workshop, all participants were able to use the tool to complete their session. While the sample size was too low to make any definitive statements and none of the participants was an actual terminal berth planner, the evaluation gave strong indications that the participants had a better experience and performed better compared to a more traditional Excel-based approach.

Furthermore, the prototype has been well-received by a number of TBA customers and the possibilities for implementing the prototype at a terminal are under investigation. As such, while more rigorous testing would have been preferred, we can say that so far, the prototype has performed well on every level of evaluation it has been subjected to so far.

Chapter 9

Conclusions

This chapter lists the conclusions on the research presented in this thesis. First, the conclusions to the research questions will be discussed. Then, some recommendations will be made to TBA. Finally, the research approach will be evaluated.

9.1 Conclusions: research questions revisited

This section will list the conclusions to the research questions defined in chapter 1. All of these questions were answered in previous chapters.

The main research question for this thesis was:

What kind of decision support tool should be designed to improve container terminal berth planning and the handling of information required to make such plans, and what prototype of such a tool can be designed?

In order to answer this question, it was decomposed into two sets of sub questions. The first set deals with *what* should be supported by such a tool; the second set deals with *how* it should be supported. First the conclusions to the sub questions will be listed, and then some final thoughts on the main question will be discussed.

- 1. *What is the current state of affairs in container terminal berth planning?* This research question can be answered by going through the following sub questions:
 - (a) What is the role of berth planning in terminal operations?

Berth planning is the problem of assigning a berth location and berth time window to visiting vessels, the arrival times of which are dynamic, in such a way that contractual obligations to these vessels are fulfilled, and with the lowest possible costs down the terminal operating chain. The berth plan has a heavy interdependence with mostly the yard plan, but also with labor and equipment plans. The berth planner often plays a central role in intra-organizational and extra-organizational communication.

(b) How is container terminal berth planning currently organized and performed? The type of workers performing berth planning tasks ranges from former dockworkers to true 'puzzlers'. Often the plans are coordinated in daily cross-departmental meetings and bilateral communication, but in many cases the berth planner does not have the required information at his disposal. The plans are usually made on whiteboards or in Excel based on rule of thumb. Much of the information used is either late, inaccurate, ambiguous or uncertain. The planner usually fills in the 'gaps' based on experience and intuition.

- (c) What are the opportunities and challenges? The main opportunities are:
 - to plan in a more dynamic way, by looking ahead more and considering more alternatives, risks and contingencies;
 - to achieve a better alignment between the various plans, where possible at an early stage;
 - to improve information support by linking available information;
 - to improve information support by getting more information or getting information earlier, from both fellow planners as well as customers;
 - to improve information support by developed better ways of dealing with early and incomplete information;
 - to improve decision making strategies on the long term, by evaluating past decisions, practicing for future situations and changing best practices;
 - to improve communication between planners;
 - to improve the alignment between value and contract incentives.

The main challenges are:

- difficulties in effecting change in organizations;
- difficulties in planning under uncertainty;
- unavailability of data on terminal operations;
- difficulties in evaluating berth plan quality.

In short, berth planning is very much a human task for which computer support has not been very developed yet.

- 2. *What would be a suitable design approach for a berth planning decision support tool?* This research question can be answered by going through the following sub questions:
 - (a) What approaches to berth planning decision support have already been explored and what are their merits?

Existing scientific publications on container terminal planning are mostly operations research studies. This is no different for berth planning. In such studies, berth planning is formalized into mathematical equations which are then solved. There exists a significant gap between these methods and reality however. In these studies:

- Sub-problems are often optimized in isolation;
- Unjustified assumptions are made that information exists, that it is available digitally, and that this information is perfectly accurate;
- Solutions are unable to properly handle uncertain or incomplete information, which is often the only kind of information available in berth planning.

Consequently, existing scientific work on berth planning has had very little impact on actual berth planning.

- (b) Would another approach to berth planning decision support be more suitable?
- As there is no system available that can solve berth planning problems by itself, the only viable way of offering support is a process where both tool and the human planner contribute to the decision making process, and that therefore some form of interaction between human and tool is required. This has the added benefit of being able to design a tool that can improve the planners' understanding of the problem and may assist in the development of new best practices, as well as in making communication between planners and other planners or outside parties easier.
- (c) What kind of design principles can guide the design of a berth planning decision support tool under such an approach?

In such an approach, ten design principles may guide (rather than restrict) the design of a berth planning decision support tool:

- 1. Exploit the way in which human and computer can add to each others' capabilities
 - 1.1. The planner as the director of the decision process: ensure system transparency
 - 2.2. The planner as the director of the decision process: enable planner control
 - 3.3. Prevent information overload: planner-controlled information filtering
- 2. Provide an architecture that facilitates different forms of the planning task
- Enable the handling of information with varying levels of information quality
 1.1. Enable the concurrent consideration of multiple scenarios and alternatives
- 4. Enable decision support in all plan design stages
 - 1.1. Link information to goals and the extent to which they are met
- 5. Enable decision support that acknowledges the existence of other interrelated planning decisions
- 3. What prototype can be developed based on these principles, and how would this prototype assist in berth planning?

A prototype tool was created that implemented a subset of these principles, based on a subset of the functionality required for successfully creating berth plans. The tool is a full-fledged and functional application created in Java, spanning about 10,000 lines of code. The focus of the prototype was to visualize the various information relevant for the plans, and to enable the planners to interact with this information. This was done in such a way that it allows them to not only explore the information, but also to explore various possible decision alternatives and their consequences.

This prototype was evaluated in a workshop with TBA staff. While the sample size was too low to make any definitive statements and none of the participants was an actual terminal berth planner, the evaluation gave strong indications that the participants had a better experience and performed better compared to a more traditional Excel-based approach. Furthermore, the prototype has been well-received by a number of TBA customers and the possibilities for implementing the prototype at a terminal are under investigation. As such, while more rigorous testing would have been preferred, we can say that so far, the prototype has performed well on every level of evaluation it has been subjected to so far. It can therefore be concluded that an interactive approach to berth planning decision support seems very promising and deserves more research attention.

9.2 Recommendations for TBA

Based on this research a number of recommendations can be made. These most important of these recommendations deal with the further development of the tool and the way in which it can be rolled out. 1. Use the tool as a gateway: try to create buy-in from a terminal and develop further by working closely with users

There are several ways in which the tool can be improved and extended. Having the opportunity to work closely with a terminal in further development could be very valuable for a number of reasons:

• Requirements elicitation

Having the tool being used somewhere may save great deals of effort in requirements elicitation. When the tool is actually used is when new uses for existing features may be discovered, or when users may perceive and articulate new needs.

• Data collection

The tool can be used as a data collector, that can be used to calibrate the forecasting abilities of the tool. This may include yard state predictions or handling time predictions for example.

• Interaction studying

Little is known about what planning strategies terminal planners would actually employ when interacting with the tool. Studying them may yield new insight into how they can best be supported in their tasks.

- *Financing of further development* Having a terminal participating in the project may fund further development.
- 2. Strive for the tool to be properly embedded into an organization

As discussed above, there may be many benefits of the tool that relate to the organization of berth planning. This includes evaluation and communication. For these reasons, as well as for performing the actual planning in some cases, organizational change may be needed. In order to have the customer reap the most benefit out of the tool, care should be taken that the right organizational processes are in place.

3. *Extend the functionality of the tool, but do not take the currently implemented features for granted* As discussed earlier, the tool is just one of many possible implementations of the design principles. In the design process, several choices were made based on a creative process rather than irrefutable scientific truths. Literature on prototyping insists that it is good engineering practice to reconsider such design choices, and not to get locked in by choices made during the prototype design stage.

The possibilities for redesign of the functionality in the prototype must of course be balanced with the development of new functionality and with concerns relating to time-to-market. Still, the opportunities that may lie in reconsidering earlier design choices must not simply be ignored.

9.3 **Project and Process Evaluation**

This project has been quite an undertaking. It went through several stages before the final shape and subject were determined. In the first month, all that was certain was that it was going to be about information use at container terminals and the application of visualization. After some time, it was narrowed down to berth planning. Still, it took half a year from the start of the project before it was even apparent that the outcome of the project was going to be a full-fledged berth planning application. Some visualization experiments were started 4 months after the start of the project, and those were followed by 3 solid months of coding to produce the berthplanner demo. Before finishing work on the thesis, two more months were spent on a project actually conducted as a direct result of the efforts made for this thesis project before the thesis itself was even finished.

This process of the subject being somewhat in limbo for that extended amount of time had an impact on the way the project was conducted. Due to changed heading in the project, there was a certain urge to keep on searching for literature matching these new ideas. In the first period, a lot of literature was explored and documented about container terminals. This survived as the first chapter of this thesis. Then, large amounts of energy were invested in researching and documenting problem solving, which survived as appendix A. The next 'fad' was uncertainty research, then visualization research, human factors and situation awareness research, heuristics, and finally, intelligence amplification and DSS research. While all of these investigations have had their role in the prototype becoming the way it is now, the relevance of some of these investigations was less than others. Even with those left out, tying all these streams together at the end of the project turned out to be a sizable task.

Another effect this had was that the research sequence was not in the right order. The most detrimental effect occurred on the design principles. These principles were the result of many discussions early on in the project, but never really were written down until after the design and workshop had already taken place. It was not common practice in any of the methodologies found or in the systems engineering thesis rigor to use design principles in this way (although it might be a good idea in the future), and the role they could play in the project was realized too late.

9.3.1 Research limitations

The factors above led directly to some limitations in the research, in addition to the extended run time of the project.

First of all, the large amount of literature meant that very unfortunate trade offs had to be made in what could in the end be featured in the thesis, the length of the thesis, and the readability of the thesis. In the end I chose to optimize for this last factor and hope I have succeeded in putting down a story that flows logically, even though it flows on for quite some time.

Secondly, conducting the thesis project in this 'Brownian motion' means that the design process was not very formal, while the requirements of the thesis are that it should be written down as if it were. Again, this was done to the best of my abilities but here too I ran into limits of what was possible. "In the early stages of a discipline or with significant changes in the environment [...] existing knowledge is used where appropriate; however, often the required knowledge is nonexistent (Markus et al., 2002). Reliance on creativity and trial-and-error search are characteristic of such research efforts." (Hevner et al., 2004) This was research in a field where the existing knowledge base was small. Therefore this was a design science research project where routine system building was not possible yet. I used existing knowledge in the form of all kinds of literature on the design of HCI systems and HCI-like systems, information design, visualization and theory on decision making. I used observations from the field. However, creativity and trial-and-error have played a big role in this thesis project and would continue to do so for a quite some time if the tool were to be developed further.

Finally, there were scheduling issues. The terminal visits were hard to arrange during the summer holiday period, while the evaluation sessions were arranged in the Christmas holiday period. It is unfortunate that it was not possible to conduct the workshop with actual planners, or with more TBA staff for that matter. With some staff being out for the holidays and others canceling due to being snowed in their homes, it was really bad luck that only seven managed to participate.

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Appendix A Human decision making: Simon's views

Traditional science as it has been practiced in the three centuries after Newton can be called natural science (Simon, 1996): it deals with the study of nature. Its goal is to produce a body of knowledge on objects or phenomena in the world, their characteristics and properties, and their behavior and interactions. However, the world in which we live today is in many ways no longer a natural world: "The world we live in today is much more a man-made, or artificial, world than it is a natural world. Almost every element in our environment shows evidence of human artifice. The temperature in which we spend most of our hours is kept artificially at 20 degrees Celsius; the humidity is added to or taken from the air we breathe; and the impurities we inhale are largely produced (and filtered) by man." (Simon, 1996, page 2). Even things considered to fit under the moniker of nature can in fact be said to be artificial: "a forest may be a phenomenon of nature; a farm certainly is not" (Simon, 1996, page 3): the corn and cattle we eat are artifacts of our own ingenuity.

If our world is indeed artificial as well, and natural sciences deal with the study of a natural world, should we not also need a science to describe the artificial world? It is only fitting that after the traditions of natural sciences were established by Isaac Newton, a man who is as much a polymath was responsible for establishing many traditions of the "sciences of the artificial" (Simon, 1969). Simon discusses how we can study this artificial world from a scientific point of view, how it is designed, and how he helped produce a body of scientific research and rigor on this very design process.

A.1 An artificial world: on the design of artifacts

Simon discussed how a certain pejorative air exists around the word artificial, and suggests that this is a result of mankind's mistrust of its own creations. This air may still be around today; it is therefore important to note that *artificial* here refers to something being man-made as opposed to natural. It deals with the results of human *artifice* being applied in order to produce *artifacts*. Simon argues that artificial objects are the central objective of engineering activity, and more specifically, prospective artificial objects having certain desired properties. However, this applies to design in general rather than engineering alone. Simon's theories on design therefore are akin to engineering science, but also have differences. However, the main point is that rather just thinking of objects in terms of what they are, engineering as well as design deals with how things *ought* to be in order to attain *goals* and to *function*. "Engineering, medicine, business, architecture and painting are concerned not with the necessary but with the contingent - not with how things are but with how they might be - in short, with design." (Simon, 1996, page xii)

Design deals with the creation of things that are not there yet. All kinds of products are designed: an mp3 player, a glass or a new version of a computer operating system are examples of products that are designed, for which products performing similar functions already exist. Nuclear fusion reactors or Mars landers are designed while products with similar functions do not yet exist. But design is done on a more basal level as well in everyday life: when one cooks, one designs the meal: the quantities of each ingredient used are design choices, and a tasty meal is a design objective. External constraints are defined by the availability of ingredients and kitchen equipment, and internal constraints by the preferences in taste of those who are supposed to eat the mail. An earlier design may be reimplemented in the form of a recipe, or a new one may be constructed: people experiment. There are differences between designs: some may be complex, some less so. Some designs are applied to known design domains, while others wander into uncharted territory. Some designs are made by professional designers, while others designs are said to be made by "naïve" (Newman and Lamming, 2008) designers.

A.1.1 The elements of design

Design theory describes what design is, and what characteristics it displays. Simon (1996) describes the artificial world as being centered on the interface between an inner and an outer environment. The inner environment is characterized by constraints and objectives, while the outer environment is characterized by fixed parameters. These parameters produce a set of possible worlds, each of which is then an alternative. When designing, one can consider possible worlds, in other words, worlds that meet the constraints of the outer environment. The goal of design is to find the world within this set of possible worlds that provides the best fit to the objectives and constraints of the inner environment. In other words, we can talk about design objectives, design constraints, and a problem space.

When characterizing design in this way, we can apply it to a great number of activities. "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state." (Simon, 1969, page 55). Following from this objective of design activities, a problem is then a gap between an existing state and preferred state. Some definitions also explicitly include the gap between an expected state and desired state (Enserink et al., 2004), although it can be argued that existing states include expected states. Alexander (1982) argues design is commonly associated with giving form to some concrete response to a need or problem. We can speak about urban design, engineering design, product design. According to him, men do not usually think of design when considering the decision-making process. However, Alexander argues they are closely related.

A.2 Decision making as a design process

In his view, it only takes one step up the ladder of abstraction to recognize design as a stage in the decisionmaking process: "Design can therefore be viewed as an integral part of decision-making. After all, the choice between alternative courses of action, always taken to be the focus of the decision, cannot take place without a set of options among which to choose." He identifies design with the creation of alternatives. However, much of engineering design methodology clearly includes choices between design alternatives in the total design process, as the finish of this process is a final design (Dym and Little, 2004). We can then think of decision making as an instance of a design activity. Simon (1996) very clearly included the choice between alternatives within his description of artificial science. And indeed, much of Simon's account of design deals with making decisions, but he considers the opposite of Alexander: design is not part of decision making, but decision making is part of the design process.

The first stage of this process consists of determining an agenda, setting goals and the generation of possible courses of action; Simon calls this stage *problem solving*. The second stage consists of evaluating these courses of action and making a choice; according to Simon, this is generally called *decision making*. Whether you call this overarching process design or decision making is then a moot point: any complete design or decision making process consists of generating alternatives and choosing between them. In that sense, they are identical. Simon considers then that a design is usually shaped in a hierarchical way, and that several design steps are to be placed somewhere in this hierarchy. Each stage is subdivided into a generative phase and a test phase. A design process is then a series of consecutive generator-test cycles. The manner in which these cycles are subdivided determines the design approach: are subproblems designed first in detail before the overarching design is considered, or is the overall design worked out in detail first before the detailed designs of sub components are considered?

A.2.1 Limits on decision making: generation of alternatives and the choice between them

As discussed above, design, and indeed decision making, can be seen as the identification of possible alternatives based on external constraints, and the choice between these alternatives based on a set of internal goals and constraints. Defining design or decisions in this form should be familiar to many readers with an engineering or operations research background: they are the same as the building blocks for optimization algorithms. There, the objectives are defined by utility or objective functions, and the search space is a subspace defined by the constraints on a larger Euclidean space. Simon considers two distinct ways to solve such optimization problems: by optimization algorithms that are guaranteed to find the best answer to the given problem, and by heuristics. He considers the former to stem from the Operations Research (OR) domain, and the latter from the Artificial Intelligence domain. He lists examples of these OR methods as linear programming, dynamic programming, queuing theory and control theory. Examples of AI techniques are hill-climbing, genetic algorithms and neural networks.

In Simon's view, in order to find a suitable solution, OR methods often need to simplify problems to a greater extent than AI methods need to. While AI methods can therefore handle more complex problem representations: this comes at a price: they are not guaranteed to find the 'best' solution. Instead, their goal is to find a good solution in a reasonable amount of time. This difference between optimization and heuristics is not only visible in computer decision making procedures: it applies to human decision making as well. Two central concepts from Simon's work on economics and organizational behavior, which earned him a Nobel prize, are those of *bounded rationality* and *satisficing*. The former deals with limits placed on the specification of a problem, the latter with the limits on finding solutions in the solution space.

A.2.2 Bounded rationality

"The capacity of the human mind for formulating and solving complex problems is very small compared to the size of the problems whose solution is required for objectively rational behavior in the real world - or even for a reasonable approximation to such objective rationality." (Simon, 1957, page 198) While prescriptive approaches on problem solving have traditionally focused on some idealized situation, empirical research placed more emphasis on the limits on human rationality. "These limits are imposed by the complexity of the world in which we live, the incompleteness and inadequacy of human knowledge, the inconsistencies of individual preference and belief, the conflicts of value among people and groups of people, and the inadequacy of the computations we can carry out, even with the aid of the most powerful computers. The real world of human decisions is not a world of ideal gases, frictionless planes, or vacuums. To bring it within the scope of human thinking powers, we must simplify our problem formulations drastically, even leaving out much or most of what is potentially relevant." (Simon et al., 1986, page 2) Under bounded rationality, the way we structure and describe the problems we encounter can not match their entire scope.

A.2.3 Satisficing

The latter of the two concepts, satisficing, deals with the limits on finding solutions in the solution space. Simon introduced this word because there seemed no suitable term to describe decision methods that look for good or satisfactory solutions instead of optimal ones. Simon et al. (1986) argues that while no one would settle for 'good' when one can get 'best', 'best' is usually not available in practical situations. While we sometimes have ways of generating all alternatives possible and evaluating them, the number of alternatives available makes it computationally infeasible to evaluate them all. This applies to human as well as machine computation. Making a decision earlier based on a limited search may provide more benefit than a decision based on an evaluation of all alternatives that took longer to complete. Absolute limits on the available search time especially requires search methods to make the best possible use of the available time, by searching in a 'smart' way; searching the solution space in a 'dumb' way and then stopping halfway is likely to yield inferior results. For these cases, the centuries-old adagio given by Voltaire (1764) applies: "the best is the enemy of good".

When using satisficing approaches, the expected length of search hardly depends on the total size of the problem space. The specified standards of acceptability are more decisive: "The time required for a search through a haystack for a needle sharp enough to sew with depends on the density of distribution of sharp needles but not on the total size of the stack." (Simon, 1996, page 120)

A.3 Ill-structured problems

The prerequisite for optimized decisions - perfect information about goals, states and constraints - is often not met in real situations. Rather the opposite: for many problems, the goals can not even be properly defined, nor can it be evaluated whether actions contribute to meeting goals. After Reitman (1965) coined the phrase 'ill-defined problems', the scientific debate on this issue was opened. More awareness grew of the ill-definedness of many everyday problems.

For example, even the 'tasty dinner problem' introduced at the beginning of this chapter can be called an ill-defined problem (Holyoak and Morrison, 2005): it is often unknown what actions will lead to a tasty dinner, and the opinions of those eating the dinner may vary over time. Most people cook based on intuition, experience and rule-of-thumb. The 'scientific' cooking style called *molecular cooking* that has been rising to prominence in haute cuisine for the past decade (Vega and Ubbink, 2008) is therefore a noteworthy development from a design perspective. With an almost prophetic flair for the dramatic, Escoffier (1907) predicted that "cookery, whilst continuing to be art, will become scientific and will have to submit its formulas which very often are still too empirical, to a method which leaves nothing to chance." It seems that with this introduction of molecular cooking, the designers of tasty meals are professionalizing; it remains to be seen whether it will live up to the ambitions laid out by Escoffier.

In the mean time, ill-defined problems are still treated by making decisions without the availability of perfect information. An exact formulation of many problems therefore does not exist, due to their illdefined nature. The problem formulation used to guide the search for alternatives and the choice between them is therefore as much decided by the problem as by the designer. Simon continued research on the issue and focused on what he called the 'structure' of problems. He thereby morphed the definition into that of 'ill-structured problems' (Simon, 1973). He relates this structuredness of problems mostly to the problem spaces suitable for defining goals, knowledge about the problem domain, state transitions, and the evaluation of states. This last point also raises the issue of computability; according to Simon (1973), we may be able to consider a chess move as a structured problem if we can evaluate the results of a move. However, as long as computational limits prohibits the evaluation of an entire game, chess will continue to be an ill-structured problem.

When looking at problems this way, one can generally claim that a problems' structure is ill-defined: "It is not exaggerating much to say that there are no Well Structured Problems, only Ill Structured Problems that have been formalized for problem solvers." (Simon, 1973, page 186) They argue that the only well-structured problems we use are idealized versions of ill-structured problems. This view has lead to allegations that the real problem solving occurs in the transition from ISP to WSP. Although Simon (1973) acknowledges that a large part of problem solving occurs in this transition, he refutes their absolute truth. However, even after the structure of a problem has been defined, multiple *representations* of it are possible. The next section will discuss how each of these representations may produce radically different results in how humans deal with them.

A.4 The representation of problems and the simulation of solutions

As discussed above, humans as well as machines solve problems by structuring it into a problem space, leading to a search for alternatives in this redefined problem space. However, even for identical problem spaces, multiple representations of this space are possible. Newman and Lamming (2008) discusses this in terms of 'mental models' of the problem, based on Simon's ideas on design and empirical research on how people solve problems. Simon (1996) discussed how bounded rationality places limits on the problem representations humans can use. For both human and machine problem solving, the chosen structure as well as its representation is a human construct; the chosen solution therefore depends on the mental model formed by humans. The problem representation is therefore key: "solving a problem simply means representing it so as to make the solution transparent" (Simon, 1996, page 132). Simon credited to an article by Amarel (1966) for this idea of representation, and developed it further in years of empirical research on decision making. To get some sense of the difference between problem structure and problem representation, consider a problem introduced by Simon (1996) and later rebranded as 'the game of 15' (Norman, 1993):

Suppose a game, that is played by two players. The 'pieces' for the game are the nine digits - 1 through 9. Each player takes a digit in turn. Once a digit is taken, it cannot be used by the other player. The first player to get three digits that sum to 15 wins.

In a sample game, player A takes 8. Player B takes 2. Then A takes 4, and B takes 3. A takes 5.

Suppose you are now to step in and play for B. What move would you make?

Based on this representation, the solution is obviously not transparent for most humans. It involves tracking which numbers are taken, which are still available, which numbers you have already chosen, and what number each player would want to pick in order to reach 15. However, when this problem structure is represented in a different way that should be familiar to many people, the solution becomes transparent immediately:



Figure A.1: The game of 15 as an isomorph of Tic-Tac-Toe

The 'game of 15' shares the same problem structure with that of Tic-Tac-Toe. When all numbers are laid out in the form of a magic Square¹, this becomes easily recognizable. The goals in both games, the initial state, the goal state, all other possible states and all possible actions are identical for both games: they are isomorphic.² Yet even though their problem structures are identical, the way in which humans approach the solutions are radically different in form as well as performance.

Another example of this is research carried out on how humans solve various isomorphs of the famous Towers of Hanoi puzzle.³ An empirical study by Kotovsky, Hayes, and Simon (1985) examined human performance in solving various Tower of Hanoi isomorphs. After the size of the task domain was ruled out as a factor of difficulty by the isomorphism, it was argued that therefore problem representation accounted for differences in required time to solve puzzles. The required time differed by as much as 16 times between the various isomorphs offered to test persons.

A.5 Criticism

The theory of design discussed here has certainly not been free from any criticism. Simon's views found an application in a wide range of fields, from economics to evolutionary biology and from cognitive psychology to social science. As a result of conflicts with existing theories, scientific debate on the validity of his theories ensued. For example, Simon's view of bounded rationality found opposition from economic theorists who regarded his view as one in support of non-rationality or irrationality and was met with disdain (Williamson, 1993). However, Williamson found at the time of writing that by then an agreement was met on the acceptance of Simon's *Homo Psychologicus* rather than the *Homo Economicus* (Simon, 1985): the acceptance of bounded rationality over rationality. It will go too far here to discuss the various criticisms on bounded rationality or design theory in general, but it is important to note that Simon's views were based on an empirical school of thought. Many other scholars lacked this empirical view; for example, Simon notes that while some economists have adapted his theories and borrowed the label of 'bounded rationality' (Sargent, 1993), they failed to "borrow the empirical methods of direct observation and experimentation that would have to accompany it in order to validate the particular behavioral assumptions" (Simon, 1996, page 39).

¹A magic square is a square array of distinct integers arranged such that all rows, all columns, and both diagonals sum to the same constant

²Problems identical in their formal structure, but different in their 'cover stories' (Simon and Hayes, 1976)

³For an explanation of the Tower of Hanoi puzzle, see http://en.wikipedia.org/wiki/Tower_of_Hanoi - accessed on August 2, 2010

A.6 Design Theory: Wrap-up and relevance

In this section, various aspects of design theory were discussed. Design theory is also relevant to the problem domain of container terminal planning itself. It was argued here that decision making process can be viewed as design processes. Planning in general and container terminal planning in particular then fit in this theory of design. This has some important repercussions. First of all, any decision support system for container terminal planning is then subject to that task domain: it will be part of the berth planner's design environment.

A well-structured design problem consists of a problem structure, which can be seen as a problem space containing states. Through actions, a transition can be made to other states. For each state, an evaluation can be made with respect to its utility. The state with the highest utility is the goal state. There are constraints borne in the inner and outer problem environment which limit transitions to same states; the collection of states which are not under constraint is the solution space. A design problem consists of finding these alternative states, and evaluating them in order to find the goal state. However, most real-life problems are ill-structured. Humans are boundedly rational and seek satisfactory solutions rather than optimal ones.

Based on the analysis of berth planning in chapter 3, it can be argued that berth planning is an illstructured problem. Therefore humans take active part in defining the problem structure. Furthermore, the berth planning problem must be represented in some way by planners, in some sort of mental model. Planners must then find alternatives, and evaluate these in order to make a decision. When considering the design of a container terminal planning decision support system from a design theory perspective, it can therefore aid the decision making process in a number of ways: in the definition of the problem structure, in the definition of a representation for this structure, by guiding the search for good alternatives, and in the evaluation of these alternatives. While there are many perspectives to look at berth planning, and I would in no way claim that the way it is handled in the main text is perfectly aligned with Simon's views on all kinds of terrains, looking at planning problems in this way was found to be very useful during the course of this project.

Appendix B

Visualization Tools

This appendix documents some visualization efforts that were made as part of the thesis project. Appendix B.1 documents two implementations of visualization concepts using a container terminal dataset. Appendix B.2 documents the implementation of the time slider that was discussed in section 7.3.5.

B.1 Focus + Context visualization concepts

As part of a visualization research project, Xerox Parc developed several *focus + context* visualization concepts in the 1990's, including the *perspective wall* (Mackinlay et al., 1991), the *table lens* (Rao and Card, 1994) and the *hyperbolic geometry browser* (Lamping et al., 1995). For work that develops further on these concepts, one can check the work of Müller (2005).

As part of this thesis project, two of these visualization concepts were tested in the container terminal domain. The table lens was tested with an implementation developed by *Inxight*¹, a Xerox Parc spin off that was bought by Business Objects, now part of SAP. The hyperbolic geometry browser was tested with an open source implementation called *treebolic*².

Table lens

The table lens example is displayed in fig. B.1. It shows over 10,000 records in a tabular overview, with each record representing a container that is located in the yard of a container terminal. The visualization chosen here focuses on the relation between vessel and yard: the *SC* column denotes the stack block in which the container is located, the *vessel* column denotes the vessel on which the container will be loaded.

The records are first sorted by their stack block, and then by their vessel. Three records from the USA vessel are focused. The mouse highlights the GGS vessel. As can be seen for example, the containers for this vessel are spread throughout the yard. Blocks F (beige) and G (purple) contain bigger numbers of containers for this vessel than the other blocks.

¹http://en.wikipedia.org/wiki/Inxight - accessed on February 7, 2011

²http://treebolic.sourceforge.net/en/index.html - accessed on February 7, 2011

Hyperbolic geometry browser

The hyperbolic geometry browser example is displayed in fig. B.2. The display is a hierarchical graph representing the same data used in the previous example; again, the whole context that is displayed contains over 10,000 containers. This time, only the locations of the containers are visualized. The hierarchy contains *yard* as the root, with stack blocks, bays, rows and tiers being the levels of depth in the hierarchy.

The focus can be shifted simply by dragging a node towards another location in the display; all nodes will be affected by automatically being given a new location in the display. In this case, the focus is on stack block Y. For this stack block, we can see several bays. Even some tier level nodes - the deepest level - are shown. Moving along the circle perimeter from stack Y to other stacks, the space allocated becomes increasingly smaller.

While this vast data can be rapidly explored in this manner, the structure in this concept - a hierarchical tree - lacks a mapping to the geographic location of the containers. While it provides inspiration as an example of how large data may be visualized, its usefulness is rather limited for this reason.



Figure B.1: The table lens ©Inxight Software, Inc.



B.2 Time Slider implementation

As discussed in section 7.3.5, the time slider is a component originally designed by Chin (2007) and was adapted for this prototype. These adaptations are both functional and architectural in nature. The functional changes include a function change for the left and right arrows; clicking them will now shift the selected time span one eight-hour shift left or right. The icons for these arrows were not transparent, resulting in gray pixels around the arrows; this was fixed. Additionally, the left and right handles icons were swapped. The label for the right handle is now displayed lower than the left, so that it will not overlap with the label for the left handle when a short interval is chosen. This is displayed in fig. B.3.

The architectural changes were necessary because the original time slider only worked with years represented as integers. The requirements for these tool included interval selection on a much finer detail level. The architecture for the tool was now changed to input and output Java *Date*³ or *Calendar*⁴ objects. The formatting of the dates is now therefore possible using a *DateFormat*⁵ instance.

³http://download.oracle.com/javase/6/docs/api/java/util/Date.html - accessed on February 7, 2011 ⁴http://download.oracle.com/javase/6/docs/api/java/util/Calendar.html - accessed on February 7, 2011 ⁵http://download.oracle.com/javase/6/docs/api/java/text/DateFormat.html - accessed on February 7, 2011



(b) New time slider implementation

Figure B.3: Comparison of old and new time slider implementations

Appendix C

Code base: classes and length of code

Table C.1 provides an overview of the classes designed for the prototype and their size.

Class name	Lines of Code	Class name	Lines of Code
BerthPlanPanel	1,535	DistanceOperationModel	105
OperationsBuilder	760	ViewSelectorPanel	104
Heatmap	754	DistanceOperationEditPopup	96
BlendComposite	752	ExcelStats	90
Operation	586	TestJTimeSlider	89
JTimeSlider	571	StateControlPopUp	73
BerthPlanner	436	Bollard	64
JTimeSliderPanel	386	Contract	44
CraneModel	341	Corner	43
VesselSelectorPanel	244	TestClass	38
ContainerBlock	191	SandboxPanel	36
Yard	185	PopClickListener	31
Rule	182	MidPanel	29
CalendarBuilder	181	EditVesselPopUp	28
StateControlPanel	176	MoveContainer	26
URLResource	152	SortOperationsByArrivalTime	21
YardBuilder	144	DischargeMove	18
OperationsState	139	SliderPanel	17
Median	138	LoadMove	16
ControlsPanel	137	ContainerType	14
YardContainer	136	OperationModel	14
ScrollablePicture	128	LabelOutputter	5
JTimeSliderActions	126		

Table C.1: Overview of code classes and length

Appendix D

Questionnaire Documentation and Results

This appendix documents the questionnaires used in the workshop. First, the questionnaire as it was handed out to the participants of the workshop is shown.

General Participant Information

Female

What is your	age?		
0	0	0	0
<25	25-34	35-45	>45
What is your	sex?		
0	0		

What is the highest level of education you have completed?

What is your occupation?

Male

How comfortable do you feel working with computers?

0	0	0	0	0
Very uncomfortable	Somewhat uncomfortable	Comfortable	Very comfortable	It's second nature

Are you familiar with container terminals and their operations?

0	0	0	0	0
Totally unfamiliar	Somewhat familiar	Familiar	Very familiar	Intimately familiar

Have you ever worked in the container terminal industry?

0	0	0	0	0
No	Occasionally	>1 year	>5 year	>10 year

Do you have any experience in container terminal scheduling?

0	0	0	0	0
No experience	Some	Regular	Broad	Scheduling
	experience	experience	experience	expert

First Session

I felt like I had a good overview of the various vessels, berths and assigned cranes

0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I felt like I ł	ad a good ove	rview of the	consequences	of a choice in	n berth or cra	ane allocation
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree

I tried as hard as I could to make a good plan

0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I enjoyed mal	king the plar	1				
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I felt stressed	while making	ng the plan				
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree

I felt bored while making the plan

0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I felt the urge	to explore a	alternatives in	order to find	l a good soluti	ion	
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
When you trie	ed to look fo	or a good plan	, it was easy	to find one		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
The planning	process cos	t a lot of effor	t			
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
At the end of	the session,	I felt proud o	f the plan I ha	ad made		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I had enough	time at my o	disposal to ma	ike a good pla	ın		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I had a lot of ı	useful inform	mation at my	disposal			
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
Disagree						Agree

I spent too much time on irrelevant details instead of the main points

0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
The tool I use	ed in this ses	sion is a good	tool for bertl	n planning		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree

Additional Feedback

Please share any additional comments.

Personal Information

Providing the following information is optional. I can use it to check back later in case of any questions regarding your answers.

Name:_____

Email Address:

Second session

I felt like I ha	d a good ov	erview of the	various vesse	ls, berths and	assigned cr	anes
O Strongly Disagree	0	0	0	0	0	O Strongly Agree
I felt like I ha	d a good ove	erview of the	consequences	s of a choice in	n berth or cr	ane allocation
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I tried as hard	l as I could t	o make a goo	d plan			
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I enjoyed mal	king the plan	n				
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I felt stressed	while maki	ng the plan				
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I felt bored w	hile making	the plan				
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
felt the urge to explore alternatives in order to find a good solution						

 O
 O
 O
 O
 O

 Strongly

 Strongly
 Strongly

Disagree

when you tri	ed to look it	or a good plan	i, it was easy	to find one		
O Strongly Disagree	0	0	0	0	0	O Strongly Agree
The planning	process cos	t a lot of effor	·t			
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
At the end of	the session,	I felt proud o	f the plan I ha	ad made		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I had enough	time at my o	lisposal to ma	ake a good pla	n		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I had a lot of	useful inform	mation at my	disposal			
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
I spent too m	uch time on	irrelevant de	tails instead o	f the main poi	ints	
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree
The tool I use	d in this ses	sion is a good	tool for bertl	h planning		
0	0	0	0	0	0	0
Strongly Disagree						Strongly Agree

When you tried to look for a good plan, it was easy to find one

Additional Feedback

Please share any additional comments.

List of Figures

1.1	Overview of research methodology	4
2.1	Increasing container trade scale	7
2.2	The functions of a container terminal	9
2.3	The container terminal in an intercontinental transport chain	9
2.4	Container Lashing	15
2.5	Subdivisions of a Container Block	17
2.6	A Rubber-Tyred Gantry Crane lifting a container on a terminal truck	18
2.7	Overview of container terminal planning decisions	20
2.8	Overview of terminal stakeholders	25
3 1	An example of a berth plan in Navis SPARCS	28
3.2	An example of a larger berth plan in TBA Trafalguar	29
33	A breakdown of the vessel turnaround time or port stav	30
3.4	Berth plan effects	31
3.5	The berth plan effects chain	32
3.6	The berth plan effects chain: Service Level Agreements and Penalties	33
3.7	The berth plan effects chain: container locations in the vard	33
3.8	The berth plan effects chain: yard equipment	34
3.9	Archetype A: Single-vessel berth location choice problem	35
3.10	Archetype B: Single-vessel berth time/location choice problem	36
3.11	Archetype C: Multi-vessel berth location choice problem	37
3.12	Archetype D: Multi-vessel service time risk problem	38
3.13	Archetype E: Multi-vessel service time risk network problem	39
3.14	Berth plan information sources	40
41	Sequential planning of seaside operations	53
4.2	The Situation Awareness Model	58
43	Scenario planning	61
1.5		01
5.1	Parallel and serial systems reliability	71
5.2	The information gap	71
5.3	The information visualization reference model	74
5.4	The hardest part of communication: the last four inches	74
5.5	A taxonomy of presentation techniques for large graphical data spaces	75

5.6	A taxonomy of clutter reduction techniques	76
5.7	Multiple ways of showing uncertainty in position (a-c) and projected position (d-e)	77
7.1	The layout of the yard	92
7.2	The berth plan panel	93
7.3	Allocating a berth to a vessel in the berth plan panel	95
7.4	Allocating cranes to a vessel in the berth plan panel	95
7.5	Hovering over a vessel box in the berth plan panel	96
7.6	The scenario manager	97
7.7	The yard layout panel	98
7.8	The driving distances panel	100
7.9	The time slider	102
7.10	The heatmap panel	104
8.1	Five alternative experimental setups	108
8.1	Workshop Scenarios	111
8.2	Workshop Results: by average	114
A.1	The game of 15 as an isomorph of Tic-Tac-Toe	140
B.1	The table lens	145
B.2	The hyper tree	146
B.3	Comparison of old and new time slider implementations	147

List of Tables

6.1	Overview of Design Principles	80
7.1	Overview of task-related functionality selection	90
7.2	Overview of principle-related functionality selection	91
7.3	Overview of functionalities implemented in the berth plan panel	94
7.4	Overview of functionalities implemented in the yard layout panel	99
7.5	Overview of functionalities implemented in the driving distances panel	101
7.6	Overview of functionalities implemented in the heatmap panel	105
8.1	Workshop Results: by participant	112
8.2	Overview of Design Principles	117
C.1	Overview of code classes and length	149