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HUMAN RESOURCES MANAGEMENT IN MARITIME CONTAINER TERMINALS: OPTIMISATION METHODS AND POLICY IMPLICATIONS

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Human Resources Management in Maritime Container Terminals: Optimisation Methods and Policy Implications

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To my family.

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ABSTRACT

In the competitive environment of container transport, Container Terminals (CT) have to plan carefully the management of their resources and services in order to satisfy shipping companies' requirements. Failure to do so may lead vessel operators to re-schedule their routes calling at new promising terminals. In particular, the optimal management of human resources is a major issue in port systems having low automation and high labour costs.

This thesis aims at providing a large overview of current practices and issues concerning the management of dockworkers in the CT area, in order to suggest the analytical methods and policies for its improvement.

The focus is on the operational plan (24/48 h), which deserves special attention because it not only determines the final system cost incurred by workforce management, but it also heavily affects the ability of the terminal to achieve high levels of productivity and to provide high quality services to shipping companies.

Starting from a collaboration with two important Mediterranean Transhipment CTs, the thesis analyses features and critical issues of the human resources management problem, as it arises in these terminals, and proposes new optimisation techniques and consistent strategies to support planners in their complex decision making process.

We here present and test an optimisation model for the daily allocation of workforce, that integrates undermanning personnel with the assignment of dockworkers to shift, tasks and activities, while taking into account several operating and regulatory requirements. The testing phase shows that the optimisation model can be effectively solved within a very short time by existing solvers, giving an optimal solution for all real-size instances tested.

Next, the thesis demonstrates how manpower shortages in a day can be reduced by spanning the model planning horizon over two-days instead of using the standard daily planning horizon and by using the model in a rolling horizon fashion.

Labour regimes play a crucial role on the dynamics of competitiveness among CTs. In particular, labour flexibility is one of the most important determinants for the resulting performances of the port systems, which are traditionally characterized by uncertain and fluctuating demand. Focusing on the Italian case, the thesis devises alternative scenarios of port-labour flexibility policies and demonstrates, by means of the above optimisation model and a cost scheme, how little changes in flexibility policies can produce a better use of the resources available, reducing the gap of competitiveness between Italian CTs and those competitors that operate under more permissive regulations.

Finally, the last part of the thesis aims at investigating through empirical evidence the role played by port labour regimes (cost and regulation) in the strategic decision of a specific terminal operating system. Special attention is paid to understanding whether restrictive and limiting labour regimes can explain the tendency to port automation that is emerging in recent years. The use of multinomial logit models and a data set of 65 European CTs provides interesting insights on what strategically motivates the choice of a specific operating system rather than another one, in order to investigate important managerial and policy implications.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AGV	-	Automated Guided Vehicle
AREA	-	Terminal Area (problem variable)
ASC	-	Automated Stacking Crane
BERL	-	Berth Length (problem variable)
CAPC	-	Terminal Capacity (problem variable)
CICT	-	Cagliari International Container Terminal
COPRAR	-	Container Pre-Arrival
CSP	-	Crew Scheduling Problem
CT	-	Container Terminal
EDI	-	Electronic Data Interchange
ETA	-	Estimated Time of Arrival
EU	-	European Union
FL	-	Fork Lift
GDP	-	Gross Domestic Product
GOF	-	Goodness Of Fit
GTO	-	Global Terminal Operator
HG	-	Housekeeping Gang
HR	-	Human Resources
HRA	-	Human Resources Allocation
HRAP	-	Human Resources Allocation Problem
LABC	-	Labour Cost (problem variable)
LABR	-	Labour Regulation (problem variable)
MCT	-	Med-center Container Terminal
MNL	-	Multinomial Logit
MTEU	-	Million TEU
NCBA	-	National Collective Bargaining Agreement
NM	-	Nautical Mile
ODC	-	Operation Delay Cost
OO	-	Operational Objective
OR	-	Operational Research
OS	-	Operating System
p.a.	-	per annum

POLC - Port Land Cost (problem variable)
qc - quay craner
RTG - Rubber Tyred Gantry (crane)
RMG - Rail Mounted Gantry (crane)
RS - Reach Stacker
SC - Straddle Carrier
SO - Specific Objective
SSP - Staff Scheduling Problem
TERT - Terminal Operator Type (problem variable)
TEU - Twenty-foot Equivalent Unit
THRU - Throughput (problem variable)
TIL - Terminal Investment Ltd
TOS - Typology of Operating System
TRAN - Transhipment (problem variable)
tt - truck trailer driver
TTU - Truck Trailer Unit
UNCTAD - United Nations Conference On Trade And Development
USD - United States Dollar
VG - Vessel Gang
yc - yard craner

CHAPTER 1

Introduction to the thesis

1.1 Introduction

Since their introduction in 1955, containers have revolutionised freight transportation, because they have enabled the transport of goods worldwide with minimum cost and complexity, providing advantages in terms of security and protection of the products against losses and damages. The introduction of containers has given a strong boost in the transition to a global economy, in which multinational companies choose the most convenient location to produce their products and then to sell them to the rest of the world, making extensive use of offshoring, outsourcing and international supply chains.

Over the last two decades the use of containers in the international exchange trade has heavily increased, rising from the 50 million TEUs handled in 1985 to 527,8 million TEUs in 2011 [UNCTAD 2012]. The rate of container transportation in the world's deep-sea routes is nowadays over 62%, with some major trade routes near to 100% [UNCTAD 2012, Gunther and Kim 2006]. The main drivers of this growth are typically identified in globalisation policies, economic performances of Eastern economies, whose exportations are steadily increasing, and in the growth of the global GDP (Gross Domestic Product). In this context, the maritime transportation has achieved a key role in the exchange of goods between Asia, Europe and North-East America with the consolidation of capacity on a limited number of major trade routes (see Table 1.1).

Table 1.1 - Major trade routes 2013.

Route	West-Bound	East-Bound	North-Bound	South-Bound	Total
▪ Asia-North America	7.529.000	14.421.000			21.950.000
▪ Asia-North Europe	8.959.000	4.406.000			13.365.000
▪ Asia-Mediterranean	4.371.000	1.875.000			6.246.000
▪ North Europe-North America	2.632.000	2.005.000			4.637.000
▪ Asia-Middle East	2.802.151	1.250.446			4.052.597
▪ Australia-Far East			1.072.016	1.851.263	2.923.279
▪ Asia-East Coast South America			550.000	1.399.000	1.949.000
▪ North Europe/Mediterranean-East Coast South America			824.000	841.000	1.665.000
▪ North America-East Coast South America			667.000	574.000	1.241.000

Source: Drewry Container Forecaster Q1 & Q2 2013.

As a result of this increasing demand, shipping companies have begun to build large container vessels with the main purpose of cutting cost by achieving economies of scale [Cullinane *et al.* 1999, Notteboom and Rodrigue 2008]. Vessels with capacity of 12.000 TEUs are no longer an exception today and ultra-large carriers with capacity of 18.000 TEUs are now in service[1]. On the one side, economies of scale allow the reduction of the operating cost per container-mile and the unit cost of transporting containers. On the other side, other cost components, especially those related to the time spent in ports to perform handling operations, have the opposite trend [Gkonis *et al.* 2009]. The operating costs of such large vessels can reach over 70.000 USD per day and, in order to take advantage of the scale economies, these large carriers need to reduce the number of calls and to cut down handling times in port. Considering that ultra large container vessels normally do not stay in port for more than 24 hours, in order to complete the loading operations on time, the terminals are forced to ensure very efficient operations, dedicating most of the work to the large vessels. As stated by Bologna [2013], in most container terminals (CT), it is difficult to satisfy the requests of large vessels and the risk is that, in case of disruptions, instead of generating economies of scale, vessel gigantism will probably bring diseconomies for ports and greater problems for logistics chains. Not surprisingly, CTs directly operated by carriers, the so-called *dedicated terminals*, are now being used by large shipping lines to secure terminal performances and the reliability of their liner services [Haralambides *et al.* 2002].

[1] Maersk Mc-Kinney Moller, the world's largest container ship, has a capacity of 18.000 TEUs. The ship is deployed on a Maersk Line route connecting Asia to Northern Europe via the Suez Canal.

The Hub and Spoke system has been quickly developed to meet the needs of large container vessels, as it allows the minimization of the number of calls and the maximization of the sailing time, which means profit for the vessel operator. The Hub and Spoke system is based on two transport levels: in the first level, the deep sea vessels, also called *mother vessels*, operate between a limited number of hub ports, whereas in the second level, smaller vessels, so-called *feeder*, link hub ports with destination ports (spokes). The Hub and Spoke network topology results in the consolidation of capacity along the routes linking hub ports with a consequent increase in competition between them for more traffic.

One can easily imagine how increased transhipment traffic and economies of scale that were made possible by large container vessels have led to new port selection mechanisms, that are highly sensitive to the differences in productivity and to the reliability offered by ports. Although the competitiveness of a terminal was traditionally determined by its geographic location and its physical characteristics, now efficiency and speed in handling operations have become the most important determinants in the choice of ports operated by shipping lines [Cazzaniga Francesetti, 2005]. Therefore, CTs attracting the largest shares of traffic are the most competitive, that is, those which can guarantee to port users the higher efficiency and reliability. In the maritime container sector, where the transport service is organised by time schedules, efficiency for a port means above all respecting scheduled berthing times. In order to maintain the reliability of the service, respect published times in official schedules and offer efficient services to their customers, the adherence to the time schedule is a major issue for vessel operators. Delays occurring at ports can negatively impact on the reliability of the liner service [Notteboom 2006, Notteboom and Rodrigue 2008], leading to additional operating costs for the vessel operator and to extra logistics cost for the customers [Vernimmen *et al.* 2007]. Lower-than-expected productivity and work slowdowns may result in delays and vessel companies shifting their ports of call to other ports that are not experiencing such problems.

Nowadays, the container market is controlled by few large shipping companies with a strong bargaining power in respect to port operators; the first ten companies control over 60% of the total market (Table 1.2). In a competitive environment where shipping lines have the choice of using more than just a single terminal for their cargo operations, a CT faces the constant risk of losing its customer base [Wang and Cullinane 2006].

In order to re-gain bargaining power and to face the increasing competition, horizontal integration between terminal operators has come into use, determining the entry into the market of Global Terminal Operators (GTO). At present, there are few port authorities that directly operate their own CTs, in fact most of them are acting as landlord ports in which CTs are given in concession to private terminal operators [Talley 2009]. Table 1.3 lists the world's ten largest GTOs in 2011. The four largest GTOs handled collectively more than one quarter of the global container throughput.

Table 1.2 – Top liner shipping 2013.

Rank	Shipping Operator	TEUs	Share (%)
1	APM- Maersk	2.608.470	14,8
2	Mediterranean Shipping Company	2.373.983	13,4
3	CMA CGM Group	1.500.602	8,5
4	Evergreen Line	817.848	4,6
5	COSCO Container Lines	788.375	4,5
6	Hapag-Lloyd	728.673	4,1
7	Hanjin Shipping	647.541	3,7
8	APL	641.642	3,6
9	CSCL	593.438	3,4
10	MOL	545.100	3,1

Source: alphaliner.[2]

Table 1.3 - Ranking World's Largest Container Terminal Operators 2011.

Rank	Operator	Million TEUs	World Throughput (%)
1	PSA International	47,6	8,1
2	Hutchinson Port Holdings	43,4	7,4
3	DP World	33,1	5,6
4	APM Terminals	32,0	5,4
5	COSCO Group	15,4	2,6
6	Terminal Invested Limited	12,1	2,1
7	China Shipping Terminal Development	7,8	1,3
8	Evergreen	6,9	1,2
9	Eurogate	6,6	1,1
10	HHLA	6,4	1,1

Source: Drewry Maritime Research (2012).

In this competitive environment, CTs that want to remain competitive and attractive in the eyes of the shipping companies must offer 24h/7d efficiency. They ought to plan carefully the management of their facilities and services to satisfy shipping companies' demands. Failure to do so will probably lead customers to re-schedule their routes calling at new promising CTs. Today, the only way to remain competitive is to offer efficient and reliable services, to ensure short turnaround times and to contain operating costs.

In particular, the optimal management of human resources (HR) is a major issue for CTs: behind the equipment there are always operators, performances of operators determine the

[2] http://www.alphaliner.com/top100/.

performances of the terminal. Excluding few CTs with high automation and restricted human activities, as for example Delta Terminals in Rotterdam or Altenwerder in Hamburg, most of the CTs are today based on human labour. Therefore, human labour has a crucial role in determining not only the daily efficiency of a CT, but also the long-term dynamics of its competitiveness. In manned CTs, dock labour represents the main cost item with an incidence on total annual operating cost ranging from 50 to 75 percent [Van Hooydonk 2013, Barton and Turnbull 2002, Castalia 2012], whereas labour performances directly affect turnaround times of vessels in ports and, consequently, the possibility to respect times scheduled with shipping lines. An optimal workforce management is thus essential to ensure efficient operations while containing and, possibly, minimizing operating costs. However, managing manpower is not an easy task in terminal activities that are traditionally characterized by uncertain and fluctuating demand. CTs have to be manned 24 hours a day and numerous workers with diverse cost and abilities have to be assigned during the various shifts to activities with different characteristics and priorities, while satisfying a number of operating and regulatory constraints. In addition, we find trade union requirements to plan workers' shifts months in advance when the work demand is still highly uncertain. This requirement further complicates the planning process and leads planners to ask for a greater flexibility in the daily management of the workforce.

The general aim of this thesis is to show that operations research methods and slight policy interventions can lead to significant improvements in the management of dockworkers and in the resulting performances of CTs.

1.2 Background

During the last decades, a significant amount of studies have investigated planning problems occurring at CTs. Several survey papers that provide an overview of terminal logistics processes and operations [Ramani 1996, Murty *et al.* 2005, Gunther and Kim 2006] and/or a review of state-of-the-art methods for their optimisation [Meersmans and Dekker 2001, Vis and De Koster 2003, Steenken *et al.* 2004, Vacca *et al.* 2007, Stahlbock and Voß 2008, Bierwirth and Meisel 2010] are available. The majority of these studies deal with OR methods to address operational planning problems such as Berth Allocation, Quay Crane Assignment and Scheduling, and Routing Problems. Although the various planning problems are highly related one another, they are usually treated as independent problems.

Only recently some attempts of integrating various planning problems have been made [Won and Kim 2009, Murty *et al.* 2005, Fancello *et al.* 2011].

Surprisingly, although the crucial role of dock labour in terminal activities is well recognised in literature [Notteboom 2010, Barton and Turnbull 2002], very little research has so far addressed the problem systematically [Stahlbock and Voß 2008]. Even though there is plenty of literature on workforce management in several fields [Ernst *et al.* 2004], in the last decade only a handful of studies faced the Human Resources Allocation Problem (HRAP) as it arises in CTs. Moreover, only one of these studies addressed the specific problem of the shift scheduling of dockworkers in CT activity [Legato and Monaco 2004]. However, although this study is the closest to our research, it neglects some fundamental issues of the HRAP in CTs. The existence of diverse levels of priority among activities and of diverse abilities among dockworkers is completely overlooked. In addition, the fundamental issues of potential manpower shortages occurring in the daily terminal activity and their economic impact on operation delays are not investigated. As a result, no policies or analytical strategies have been proposed so far to improve the management of dockworkers in CTs.

1.3 Definition of the research problem

This thesis aims at providing a large overview of current practices and issues concerning the management of dockworkers in the CT area, in order to suggest the analytical methods and policies for its improvement.

The focus is on the operational plan (24/48 h) that deserves special attention because it not only determines the final system cost incurred by workforce management, but it also heavily affects the terminal ability to achieve high levels of productivity and to provide high quality services to shipping companies.

Starting from a collaboration with two important Mediterranean transhipment CTs, i.e. Cagliari International Container Terminal (CICT) and Gioia Tauro Med-center Container Terminal (MCT), we analyse the features and the critical issues of the HR management problem, as it arises in these CTs and, more generally, in Italian CTs, in order to propose new optimisation techniques and consistent strategies to support planners in their decision making process.

We develop an optimisation model to determine the daily allocation of dockworkers to shifts, tasks and activities, while taking into account operating rules and regulatory requirements. Compared to the closest study available in the existing literature, the model presents several sources of originality [Legato and Monaco 2004, Monaco *et al.* 2009]: the fundamental issue of manpower shortages is introduced in the model as a problem decision variable, a new cost formulation for terminal workers is proposed taking into account operators' productivity, activities' priority and complexity, and new regulatory constraints are arranged. For the first time the research brings into light the fundamental issue of manpower shortages arising in the activity of a CT and it shows, by means of a cost scheme, the practical impact of workforce undermanning on port operation delays and the related costs in realistic cases of shipping companies experiencing larger-than-expected berthing times. We demonstrate how manpower shortages can be reduced by spanning the model planning horizon over two-days, instead of one day, and by using the model in a rolling horizon fashion.

Despite the use of optimisation techniques, in some CTs strict labour regulations and insufficient flexibility policies can prevent an optimal use of the available resources, leading to a decrease in the level of service offered to vessel operators and to a consequent decline of the terminal competitiveness. Not even an optimal resource management that is implemented through an effective analytical tool may be sufficient to ensure a competitive position for the terminal in a market characterized by competitors that operate under more permissive regulations and at lower labour costs. Looking at the Mediterranean area for example, the competition among CTs is distorted by economic and regulatory heterogeneities that place Italian CTs (we could also say European CTs) in a significant disadvantage compared to their competitors located in the southern Mediterranean. In this research we devise alternative scenarios of labour flexibility policies and we demonstrate, using our optimisation model and a cost scheme, how little changes in labour policies can produce a better use of the available resources in the daily management of a CT, reducing its gap of competitiveness. Decision-making cannot obviously be part of the research, but research findings can undoubtedly help policy makers in taking the decisions by providing them with a thorough knowledge of the problem on the basis of objective elements.

Finally, the last part of the research tries to empirically investigate whether restrictive and limiting labour regimes existing in the port area can explain the new tendency to automation that some CTs are showing in recent years [Gunther and Kim 2006]. By means of regression techniques and a data set of 65 European CTs, we verify the possibility to explain an empirical relationship between the labour regime (labour cost and labour regulation) existing in CTs and the strategic decisions concerning the choice of the adopted operating system, with a special focus on automated models.

1.4 General, Specific and Operational objectives of the research

As introduced in the previous paragraph, the general objective of this research is to provide a large overview of the practices and issues concerning the management of dock workers in the context of CTs, in order to develop methods and policies for its improvement. The main research question can be formulated as follows: *Which techniques and strategies can produce an improvement in the management of dockworkers in container terminal activities?*

To answer this main question, the research problem has been divided into four secondary questions corresponding to four specific objectives (SO) that will be deeply investigated in the various chapters of the thesis. Within these specific objectives, it is possible to further state the operational objectives (OO). Specific and operational objectives of the research are listed below.

SO-1. Formulating and implementing an analytical model for the optimisation of the daily allocation of dockworkers in CT operations.

- OO1.1 Review and critical analysis of the existing literature in the area of Human Resources Allocation (HRA) in maritime CTs;
- OO1.2 Acquisition of know-how on manpower management through the direct observation of port operations in the two CTs under analysis;
- OO1.3 Identification of features and critical issues characterizing the manpower management in CTs;
- OO1.4 Development of an optimisation model consistent with the reality for the daily allocation of port workforce;
- OO1.5 Application of the model on real-world numerical instances provided by the two CTs in question;
- OO1.6 Discussion and assessment of the application results.

SO-2. Building up a descriptive cost scheme for terminal operation delays resulting from manpower shortages occurring in the day.

- OO2.1 Identification of cost items involved in delays in port operations, from the vessel perspective;
- OO2.2 Acquisition of vessel cost data from scientific and technical literature;
- OO2.3 Construction of a descriptive cost scheme linking port operation delays, due to manpower shortages, to additional costs borne by vessels and additional logistics costs.

SO-3. Assessing and analysing the impacts of the planning horizon length on the operational management of the port workforce.

- OO3.1 Review and critical analysis of the literature dealing with the definition of the planning horizon length in port planning;
- OO3.2 Identification of a suitable length of the planning horizon in the operational management of the port workforce;
- OO3.3 Implementation of the new planning horizon length on real-world instances and comparison with the standard daily horizon;
- OO3.4 Discussion and assessment of the application results.

SO-4. Constructing and evaluating alternative scenarios of labour flexibility policies in the port area.

- OO4.1 Analysis of the Italian legislation in the port labour area and general survey on EU port labour regulation;
- OO4.2 Identification of the main limits of current port labour policies with respect to the flexibility needs required by terminal operations;
- OO4.3 Construction of alternative scenarios on port labour flexibility policies;
- OO4.4 Simulation and comparison of the manpower assignments resulting from the implementation of the considered scenarios;
- OO4.5 Discussion of the application results and evaluation of tested policies.

In addition, in order to get a broader perspective in understanding whether it is possible to establish an empirical relation between the new trend to port automation and the rigidity of the labour regime existing in the port area, we also investigate the following research question: *Is it possible to establish an empirical relation between the labour regime existing in a container terminal and the strategic decision concerning the choice of the operating system adopted?*
This research question corresponds to the fifth specific objective:

SO-5. Investigate, from a quantitative perspective, the role of variables linked to the labour regime existing in a CT in strategic decisions concerning the choice of the adopted operating system.

- OO5.1 Review and critical analysis of the literature dealing with determinants of the operating system choice in CTs;

- OO5.2 Identification and critical analysis of the different operating systems currently used in European CTs;
- OO5.3 Construction of a dataset of European CTs, including the definition and the selection of variables that are likely to affect the strategic decision on the operating system choice;
- OO5.4 Application of appropriate regression models for determining the strategic determinants in the choice of the operating system;
- OO5.5 Discussion and assessment of the application results.

The operational objectives listed above combine qualitative and quantitative approaches, and trace the same methodology followed in the development of the research:

- *Literature review.* In order to gain an insight on the methods and theories available in the field of HR management in CTs, to identify shortcomings of the existing studies and to formulate new research hypothesis, in the initial phase we have reviewed journals, technical reports and other publications related to the topic while updating them throughout the whole research.
- *Empirical observation of port activities, interviews with terminal experts and data collection.* A number of interviews organised as open discussions took place during CT visits, so as to gain a fuller understanding of the real problem and establish the practical foundation of the research. Afterwards, more focused interviews supported by a questionnaire took place with terminal managers to collect the data and the necessary information to design the optimisation model and to build numerical instances for its validation.

  As for the second part of the research, data collection has involved various secondary sources.
- *Model specification and instantiation on data collected.* The analysed problem is mathematically modelled on the basis of the relevant aspects emerged in the previous phases. These models are then instantiated on collected data in order to test the proposed research hypothesis and to evaluate alternative policies.
- *Results' evaluation and policy discussion* on the basis of the outcomes of the application.

1.5 Research methods and data

Several research methods have been used in this research:

- Desk research;
- Interviews;
- Direct observation of terminal operations during internships at CICT and MCT;
- Optimisation;
- Simulation;
- Multinomial logistic regression.

Data and information used in this research have been collected for the most part during internships at CICT and MCT and through interviews with terminal experts.
Despite the kind and generous collaboration of the two CTs, this research had to face the well-known problem related to difficulties in gathering some data, especially those related to cost factors, because of their sensitive nature and the understandable reluctance of operators in spreading such information. However, collected data and indications on costs (where it was not possible to have the precise information) have allowed us to acquire a good knowledge of the problem addressed and a considerable number of real-world instances to test the model and the various hypothesis developed in this research.

As for the second part of the research, that has required the challenging process of construction of a database comprising more than 60 European CTs, the information collected is mainly based on a combination of data deriving from official websites of CTs and secondary sources such as Containerisation International Yearbook and Dynamar reports. Besides, at a later stage several CTs taking part in the sample have been approached directly in order to validate the collected information and to overcome the problems related to missing and inconsistent data.

1.6 Overview of the thesis

Following this introductory section, the thesis is organised in 8 chapters.

In Chapter 2 we describe the costs and features of the HR management problem as it arises in Italian CT's and we present the two Italian transhipment CTs analysed in this study so as to acquire the practical knowledge of the problem addressed. In this chapter we discuss the uncertain and fluctuating nature of work demand in terminal activities and its

implications in managing workforce; we illustrate the features and limits of the two levels of planning (i.e. log-term and short-term) and explain the reasons why we mainly focus on the short-term plan of manpower. In the chapter, we also present a summary of the scientific literature dealing with the HRAP in the port area and we discuss the gaps in the state of the art.
The main purpose of this chapter is to provide the basis for the model specification in next chapters.

In Chapter 3 we present an optimisation model for the daily allocation of dockworkers in CTs. Since manpower undermanning has a crucial role in CT activity, operators shortage is modelled as one of the decision variables of the allocation problem. The ability of the model in finding optimal solutions for realistic problems is demonstrated by means of numerical test-instances derived from typical working days at CICT. Existing solvers are able to exactly solve realistic size instances within time limits imposed by planning operations.

In Chapter 4 we analyse the cost factors related to longer-than-expected working times at the terminal, distinguishing the point of view of the shipping operator from that of the terminal operator. The chapter presents a descriptive cost scheme that illustrates, from the vessels' perspective, the relationship between manpower shortages occurring in the planned day and the costs related to the extra-time spent by vessels in port to complete handling operations. The cost scheme is developed with the support of terminal experts, cost values are derived from published data, whereas average productivities are taken from the two CTs under study.
Considerations on two other important cost factors in case of vessel operation delays at the terminal, i.e. logistics cost of goods carried and increased fuel consumption, are also discussed in the chapter.

In Chapter 5 we aim at investigating the effects of the planning horizon length in the operational management of workforce in CTs. In particular, since a longer planning horizon allows the visibility of more data, we investigate the effects of using a planning horizon longer than the standard daily one in the operational management of the workforce. A two-day planning horizon is adopted so as to limit the planning horizon length to an interval in which problem data can be considered enough accurate, taking into account the uncertainty on port activities demand. The optimisation model encompassing the two-day horizon is used in a rolling horizon environment to solve numerical real-world instances. Here-and-now decisions deriving from the use of a two-day horizon are compared to those taken by using the daily horizon by means of the cost scheme in Chapter 4. The results show how operators' shortages in a day can be reduced in the model solutions if a two-day planning horizon is used instead of a standard daily one.

In Chapter 6 we investigate the effects of a greater labour flexibility in terminal operations in terms of a more efficient use of the available resources and of a reduction in operating costs. This chapter provides a general overview of port labour regulations in European countries and analyses in detail the Italian port labour regulation. The scenario of the current labour arrangements in Italian ports is compared to five alternative scenarios that are constructed by increasing the share of daily working flexibility and introducing a new type of labour flexibility, called mini-flexibility. Simulations of the manpower assignments resulting from each scenario are performed through the use of the optimisation model presented in Chapter 3, whereas economics effects of the allocation resulting from each scenario are compared through the cost scheme described in Chapter 4. Findings confirm the importance of labour flexibility for port competitiveness and support changing policies on port labour regulation, which today appears too restrictive and limiting for some CTs.

In Chapter 7 we aim at empirically investigate whether restrictive and limiting labour regimes existing in the port area can explain the tendency to automation that some CTs are showing in recent years. The decision of what operating system to use is a strategic decision that is based on several and heterogeneous factors. So far, this issue has been investigated almost exclusively from a technical point of view, while limited research has been performed in the area of the strategic determinants that lead to the operating system choice. By means of regression techniques and a data set of 65 European CTs, the chapter investigates the possibility to establish an empirical relationship between the labour regime (labour cost and labour regulation) existing in port areas and the strategic decisions on the choice of the adopted operating system. The use of regression techniques provides interesting insights on what strategically motivates the choice of a specific operating system with respect to another.

Chapter 8 summarises the results and conclusions of the study and provides suggestions for future research.

CHAPTER 2

Human Resources Management at Container Terminals

2.1 Introduction

CTs are facing increasing competition which requires more and more efficiency in operations. In particular, in hub ports, vessels operators' demands for efficient services are even more pressing. In this context, a key factor for the competitiveness of a CT is the optimal management of its resources in order to achieve high levels of service operating in compliance with various operational and regulatory requirements. In manned CTs[3], i.e. terminals in which activities are mainly based on the labour of dockworkers, an optimal manpower management is a priority in pursuing high levels of service and efficiency while containing labour cost.

In this research we are considering only dock workers, i.e. those operators involved in loading/unloading operations onto/from vessels and in containers handling operations in the terminal yard, administrative staff is not considered. Dock workers, also called blue collars, constitute about 80 per cent of the total workforce of a CT.

Notwithstanding the fact that the planning of manpower is a problem common to most organisations, the specificity of CT activity, the need of ensuring 24h/7d efficient services,

[3] Notwithstanding the rising automation tendency, nowadays the vast majority of CTs are manned. Looking at European container ports, less than 10 CTs have so far adopted automated equipment for container handling operations.

the various operating and regulatory constraints imposed by operations and regulations, and the fluctuating and uncertain nature of labour demand require a diverse and specific approach in managing port workforce.

Despite the relevance of the problem, very few scientific studies have faced this fundamental issue. This is probably due to the peculiarities of the problem addressed that is typically difficult to research for the lack of data or given to its sensitive nature.

The present chapter aims at providing a deeper understanding of the HR management problem as it arises in Italian CTs by discussing the main features that characterize it. We focus on the Italian case and we specifically analyse two important Italian transhipment CTs: CICT in Cagliari and MCT in Gioia Tauro. Internships at the two terminals and interviews with terminal experts during these years of research have allowed us to gain a good knowledge of the problem addressed, whose main features are discussed in the present chapter. Furthermore, the chapter presents a summary of the scientific literature dealing with the HRAP in the CT area and discusses the main limits of the studies currently available.

The rest of the chapter is organised in the following way. Section 2 analyses a conceptual framework on dock labour and discusses direct and indirect costs characterizing labour in port activities. Section 3 discusses the fluctuating and uncertain nature of demand in port activities and its implications in the manpower management. Section 4 illustrates the features and limits of the two levels of planning, i.e. long-term and short term, currently used for managing manpower in CTs and it explains the reason why we are going to focus on the short-term plan. Section 5 presents a literature review on HRA and staff scheduling problems in maritime CTs. Section 6 briefly presents the two Italian transhipment CTs used to set the problem addressed. Finally, concluding remarks are reported in section 7.

2.2 Dock labour in CTs

We report in Figure 2.1 the conceptual framework on dock labour as designed by Notteboom [2010]. This framework is quite useful because, despite its apparent simplicity and linearity, it contains and links all the more complex elements and factors that characterize the system of port labour in CTs. The framework follows a market-driven approach in which there are port users, typically vessel operators or shippers, who demand precise logistics requirements from terminals depending on the characteristics of their business, and terminal operators who have to meet these requirements in order not to lose traffic volumes.

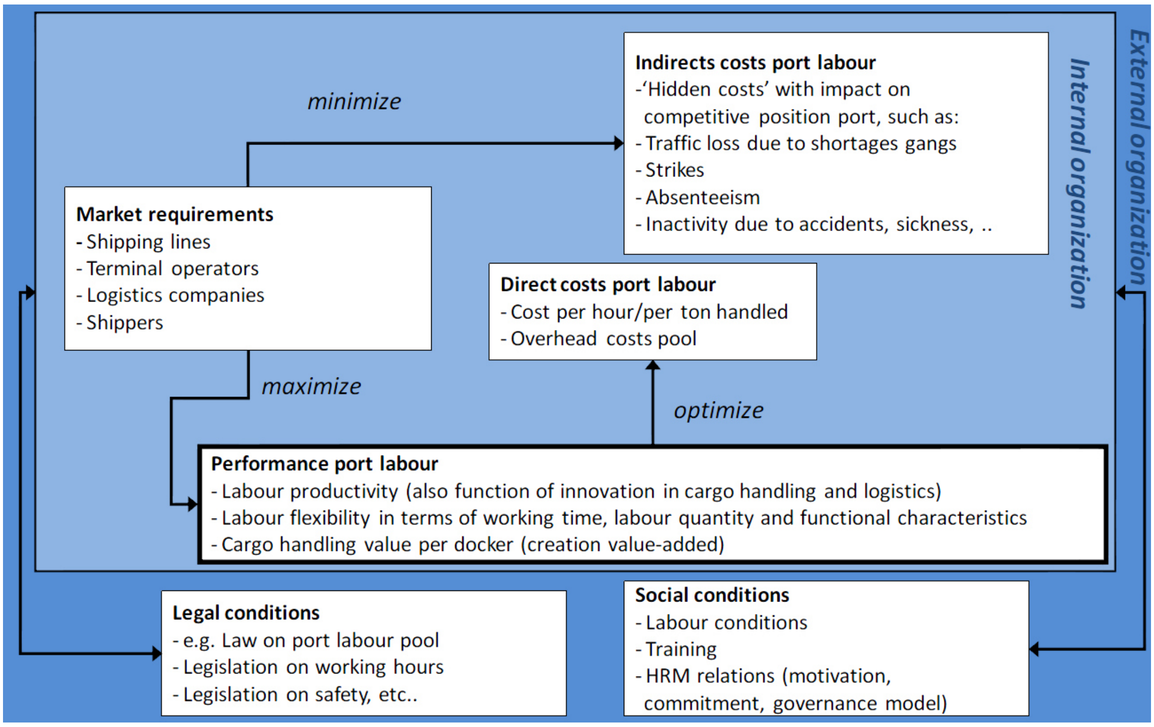

Figure 2.1 - Conceptual framework on dock labour.
Source: Notteboom [2010].

Looking at the figure, market requirements mainly concern a maximization of the performance of port labour, which in turn requires an optimisation of direct costs and a minimization of the indirect cost related to port labour. In this framework, legal and social conditions play a decisive role, because they can heavily affect the way in which resources are employed (see Chapter 6), and the resulting performances.

It is worth noting that, even though these elements are common to all dock labour systems, significant differences persist between ports in terms of labour regulation, labour arrangements, efficiency and competitiveness [Barton and Turnbull 1999]. In fact, the way in which all the elements of this framework interact with each other may vary significantly from terminal to terminal determining the specific labour system of a port.

As seen in Chapter 1, the heavy competitive pressure that characterizes the shipping sector forces container ports to negotiate cost-effective 24h/7d services with shipping companies. Port users have a well-known power in the port market and if they are not satisfied with port services, they may rapidly decide to re-design their maritime lines to exclude unsatisfactory terminals. As a result, ports have to accurately plan the management of their assets in order to meet the stringent requests of shipping companies.

Dock labour affects directly three fundamental aspects of port activity: cost, time and risk [Barton and Turnbull 2002]. In manned CTs, labour cost is the main cost item with an incidence ranging on average from 50 and 75 per cent of its total annual operating cost [Van Hooydonk 2013, Barton and Turnbull 2002, Castalia 2012]. Furthermore, even in capital-intensive CTs, labour cost frequently reaches 50 per cent or more of the total operating cost of a CT [Notteboom 2010]. Labour cost in CTs typically accounts for regular wages of dockworkers plus supplements and bonuses for overtime. This latter is on average between 1.3 and 1.5 times the regular pay, as such it should be avoided unless absolutely necessary.

In addition to the direct cost of labour, attention should be paid also to indirect costs. As stated by Notteboom [2012], a good labour system should be designed in order to minimize not only direct costs of labour but also indirect ones, which are defined by the author as *hidden costs*. Indirect costs are not easy to define as they can take several forms: absenteeism, accidents, incidents with cargo damages, strikes and shortages of workers leading to delays in handling operations. Accidents and incidents in the majority of cases are attributable to excessive workloads with fatigue and loss of concentration, or a lack of training which leads to unskilled workforce. Strikes, instead, typically result from disputes between union organisation and employers over contractual terms and labour conditions. Strikes have always been a threat for port activities as their effects can be devastating not only for the port and its users but also for the wider production chain, especially when strikes are recurrent [Barton and Turnbull 2002, Katsarova 2013].

Manpower shortages are one of the most common reasons of slowdowns in CT activities. When in a working shift the available workforce is less than the quantity of the staff needed to complete all the operations scheduled for that shift, it is said that in this shift there is a shortage. A manpower shortage makes it impossible to complete the work planned for that shift. The completion of the backlog is normally postponed to the following shifts with inevitable lengthening of vessels' turnaround times. In fact, a vessel cannot restart its travel until loading/unloading operations are completed[4]. Shortages can depend on several reasons (e.g. absenteeism, sick leave, holidays) but most of the times they derive from unexpected peaks in labour demand. Shortages are extremely costly for

[4] In order to respect the schedule, sometimes vessels can decide to leave the terminal without having completed handling operations; this practice is known as "cut and run", see Chapter 4.

shipping as they cause significant delays, unnecessary time costs for vessels in ports and further potential logistics costs due to disruptions in the production line.

Labour arrangements are decisive in determining the performance of a terminal. A careful manpower planning able to contain labour cost and to limit manpower shortages cannot be undervalued.

2.3 Uncertainty and fluctuating demand

2.3.1 Information flow

In order to plan port activities in the best way, terminal planners need to know in advance appropriate information on incoming vessels. These latter are required to send to the terminal several information items before their arrival. This information mainly concerns the estimated time of arrival and loading/unloading instructions. The most important information sent by vessels are summarised below.

- *ETA* (Estimated Time of Arrival), it contains the estimated date and arrival time of a vessel. This information is updated several times before the actual arrival of the vessel in port. Time intervals of reception are typically monthly, weekly, 48 hours, 24 hours or less. The reliability of the information increases as the actual date of arrival is approaching. The uncertainty on vessels' arrival times strongly depends on the processing time of the vessel in the previous port and transit time. For this reason, the reliability of the information increases if ETA file is sent when the vessel has already left the previous port.
- *Forecast*, it is usually included in the last ETA and contains the indicative number of moves required by the vessel.
- *Baplie*, it is an EDI (Electronic Data Interchange) message that contains information on the stowage plan of the vessel and additional information (typology and characteristics) on containers to handle in the CT.
- *COPRAR* (COntainer PRe-ARrival), it is an EDI message used by the shipping operator to instruct the terminal which containers must be loaded (COPRAR/Load) or discharged (COPRAR/Discharge). The latter contains information on containers continuation: boarding vessel and next port of call.
- *Movins*, it is an EDI message containing stowage instruction.

The knowledge of all this information is essential to allow a good planning of terminal activities. In particular, since the handling activity in a CT is closely related to the availability of vessels in dock, and then to the arrival times of vessels in port, ETAs represent the main input to determine the estimated work demand. Starting from ETAs, planners are able to know how many vessels are expected in the planned day and, on the basis of this information, they can proceed with the planning of operations. However, the problem is that this information is far from being precise.

2.3.2 Uncertainty of the labour demand

CT activity is traditionally characterized by uncertain and highly fluctuating labour demand which complicates the task of planners and consequently the effectiveness of the planning. Murty *et al.* [2005] in describing the special nature of CT activity identified three fundamental characteristics:

- Irregular distribution of the workload over time;
- Impossibility to control the precise order in which work comes due to difficulties in predicting in advance the exact time of vessels arrivals;
- Need to perform work when it arrives, i.e. when vessels arrive at the terminal. Delays in processing work have to be avoided as much as possible.

The arrival time of a vessel is a parameter affected by significant uncertainty. The level of precision in its evaluation becomes acceptable only when the actual arrival of the ship in port is approaching. Although a vessel sends to the terminal the expected arrival times through ETAs as early as the previous months, only the ETA's sent 48/24 hours before the arrival show an acceptable level of reliability. As a consequence, the arrival time in a day can be known with an acceptable level of precision only 24/48 hours beforehand[5]. The problem is that due to union agreements and labour rules, working shifts must typically be planned a number of months before their implementation, when the demand data on vessels that must be handled in the planned day is still highly uncertain. The main risk is to underestimate the demand of the day with consequent shortages of dock workers when activities must be performed. The occurrence of manpower shortages and the consequent delays in handling operations can have significant impacts in terms of additional costs for both the CT and the vessel operator. It should be noted that

[5] So far, new forecasting tools applicable in the short term (24-48h) for predicting vessels arrival times are being developed and contribute to make sufficiently accurate data on the work demand concerning the next 24 hours [Fadda *et al.* 2013].

transhipment CTs, in particular, are more sensitive to personnel undermanning and to possible delays in the service of mother vessels: the bigger the ship, the more the negative effects of port services are felt. Undermanning of resources should be avoided in managing manpower as well as overmanning. In fact, overmanning too can be inconvenient from an economic perspective and it can also be highly ineffective because of possible shortages in future shifts due to the limitations imposed by shifting policies.

The other important feature of labour demand is that it is not constant over time and may widely fluctuate from day to day. It may happen that one day the CT is almost empty, while the day before it was almost full. We experienced this during our internship at CICT. The first day we arrived, only a vessel was being unloaded on the dock, when we asked about it to the operation planners, we discovered that the previous day the terminal was almost full and several vessels had been handled.

It is clear that in order to face the uncertain and fluctuating nature of port labour demand, labour arrangements should guarantee a sufficient degree of flexibility to ensure a good match between demand and supply.

2.4 Planning manpower at two levels, flexibility and casual labour

This paragraph describes the current manpower organisation used in Italian CTs. The majority of information reported has been collected during internships at CICT and MCT and through interviews with terminal experts.

The working day of a CT is organised in shifts, typically 3 or 4, covering a 24-hour operating cycle. Dockworkers perform their activities during these shifts. The number of shifts as well as their starting and ending times may vary among terminals depending on the specific organisation of each.

The contrast between the impossibility of determining in advance and with sufficient precision the demand data that will characterize the following months of the CT activity and the obligation established by contractual clauses of planning working shifts a number of months ahead, has led terminal planners to decompose the planning of the workforce into two phases: long-term and short-term plans.

- The long-term plan is typically performed once a year, according to work rules and contractual clauses only. Demand data is not considered at this stage.

  It consists of a sequence of workdays and rest-days for each terminal worker, hereafter "internal worker". In order to face demand uncertainty, the terminal planner has at his disposal the contractual institute of the flexible shift. Internal workers in a day may be in fixed or flexible service. Workers in fixed service, from here "fixed workers", are already allocated to a specific shift in that day while workers in flexible service, so-called "flexible workers", know they have to work in that day but they are not yet assigned to a specific shift. Since the real work demand is not yet known when the long-term planning is performed, labour activities of workers cannot be planned in this phase. Figure 2.2 shows an example of long-term assignment of an internal worker working at CICT. Each line represents a month of the year, while each column represents a day of the month. The single box shows the daily assignment of the worker: worker in a day may be in fixed service (the box-code is the working shift), in flexible service (the box-code is FLX) or in day-off (the box-code is RPI or RIC).

The team spirit criterion is taken into account at this stage. Sub groups of dock workers with a good team spirit have the same long-term assignment so that they can be part of the same gang when a short-term plan is performed.

- The short-term plan is a refinement of the long-term one and is typically performed 24 hours in advance of the planned work day, when the work demand is more precisely known. It aims at specifying shifts and working activities for each operator. The short-term plan is required to inherit fixed operators from the long-term plan and to determine the shifts of operators, who are classified as flexible by the long term plan. Moreover, to face work demand peaks, a limited number of workers, hereafter "external workers", coming from external firms authorized to provide temporary port labour, can be employed for performing some tasks when internal workforce is not sufficient.

  In short, several decisions need to be taken at this stage:

  - Assignments of shifts for flexible workers;
  - Definition of the number of external workers to call;
  - Composition of gangs;
  - Definition of working activities for each worker (internal and external). It is worth noting that internal workers are usually multi-skilled, i.e. they can perform more than one task according to their qualification level (multi-skilling policies will be better discussed in Chapter 3). The task to be performed in the planned day is also determined by the short-term plan.

Needless to say that the way in which all these decisions are taken will determine the success of the assignment process and the total final cost resulting from the manpower planning.

	Operator Code: 60																														
2011	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1	RIC	FLX	II	III	RPI	RIC	RIC	II	FLX	III	RPI	I	RIC	FLX	II	RIC	RPI	I	RIC	II	FLX	III	RPI	RIC	RIC	FLX	II	III	RPI	I	RIC
2	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI			
3	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I
4	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	
5	RIC	FLX	II	III	RPI	I	RIC	RIC	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC
6	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	
7	FLX	II	RIC	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	RIC
8	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	RIC	RIC	FLX	II
9	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	RIC	RPI	I	RIC	II	FLX	
10	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	RIC	FLX	III	RPI	I	RIC	FLX	II	III
11	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	
12	RPI	I	RIC	FLX	II	III	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	RIC	RPI	I	RIC	II	FLX	III	RPI	I	RIC	FLX	II	III	RPI

Figure 2.2 - Long-term planning of a dock worker.
Source: CICT.

It is important to note that long-term and short-term plans involve different data and decisions over different time scales. For example, the sequence of workdays and off-days of each operator must be performed once a year, but at this point of time the real workload is not precisely known. Although the knowledge of the workload is more accurate 24 hours before the arrival of vessels, planning this sequence at this point of time is not allowed. On the other hand, assigning workers at working activities one year in advance may be highly ineffective. The long term decisions must be made only once a year and they cannot be changed throughout the yearly planning horizon. These decisions result absolutely binding to the next level of planning. Therefore, long term decisions are enforced to play the role of data for the operational planning, guaranteeing the right flow of information throughout the whole planning phase.

In this study we are investigating the short term (or operational) planning of HR management. It deserves particular attention because it inherits some unchangeable decisions from the long term plan, it involves the use of terminal resources considering the real work demand and it leads to the final estimations of the costs and benefits that derive from the optimisation processes. Moreover, it gives valuable room for optimisation,

because of the wide arrays of parameters and decisions involved. Conversely, there is less room for optimisation in the long-term planning, in which feasible sequences of workdays and off-days must be determined according to contractual clauses only.
Operations research methods and techniques can be really useful in supporting terminal planners in this core process.

2.5 State of the art on Human Resources Allocation in CTs

The allocation of manpower to shifts is a problem that most organisations have to face. Even if the complexity of the scheduling may vary depending on the specific needs of the organisation, its primary objectives are always the effective use of the workforce and the minimization of the resulting cost. The problem of defining the shifts of the operators working within an organisation, in order to meet the work demand, is typically referred in literature as Staff Scheduling Problem (SSP) or Shift Scheduling Problem [Slany *et al.* 2001]. Although numerous studies exist on workforce management and SSPs – they mainly concern planning models developed for specific areas of application (e.g. airline, railway and urban transportation, nurse and hospital staff, emergency crew) - only little attention has been devoted to the specific context of maritime CTs.

This paragraph draws an overview of the literature on SSPs organised into three main sections:

- The first section introduces the general SSP with a description of its main characteristics;
- The second section analyses literature on Crew Scheduling Problem (CSP) in transportation areas;
- The third section focuses on literature dealing with the human resources allocation problem in the specific context of maritime CTs.

2.5.1 The general Staff Scheduling Problem (SSP)

The optimisation of the scheduling of operators can lead to important benefits in terms of cost saving and of level of service offered to users. However, due to the complexity and heterogeneity of variables and constraints involved, the decision process tackled by the planner can be unmanageable without the aid of suitable decision support tools.

Due to its practical relevance and complexity, the SSP has been extensively investigated during the last few decades. A good review can be found in Brucker *et al.* [2011], Ernst *et al.* [2004]. Although SSPs take different features depending on the specific field of application [De Causmaecker *et al.* 2005], from a modelling perspective it is possible to identify a basic structure common to all SSPs:

- a data set;
- a set of constraints and relations among the items of the data set;
- one or more objective functions.

These three elements together constitute the basic model of the SSP. A brief description of these fundamental elements composing a SSP is given below, following the same structure illustrated in Blöchliger [2004].

The data set of a SSP consists of items, time table blocks, jobs, costs and decision variables.

- *Items* are the elements that need to be scheduled and are typically defined as entities that can only be in one place at a time. Each item has its own identification and may also include other data. Items of SSPs are typically employees or operators.
- *Time table blocks* are well defined periods of time in which operators can be scheduled. In SSPs time table blocks normally coincide with shifts composing the working day, but they can also represent breaks, travel times, etc.
- *Jobs* identify a requirement of operators over a defined period of time. A typical example of a job may be the requirement of a given number of operators performing a specific task during a working shift.
- *Costs* depend on the assignment of operators to the different time table blocks.
- *Decision variables* are the variables denoting the choice of problem solving decisions. The solution of a SSP is represented by the assignment of different time blocks to each operator.

Constraints of a SSP can be divided into two main categories: hard constraints and soft ones. The former are those that cannot be violated for any reason. In SSPs, the requirement that each operator can perform only one task at a time is a typical hard constraint. Soft constraints are constraints that can be violated maintaining the solution still acceptable. Soft constraints in SSPs may concern the duration of daily working time, in this case an optimal value and a range of acceptable values are defined. Usually, soft constraints are managed through a penalty function taking value 0 if the soft constraint is fully met or increasing its value depending on the level of the constraint violation.

The objective function measures the quality of the solution. The main objective in SSPs is always the use of the available resources in the most efficient way in order to complete all the jobs scheduled at the minimum cost. The cost of the solution is given by the sum of the costs of single assignments. Secondary objectives can be the minimization of soft constraints violation or the maximization of fairness in the assignment.

2.5.2 Literature on CSPs in the transportation area

In the transportation area the SSP is commonly known as Crew Scheduling Problem (CSP), as it mainly consists in assigning a set of basic activities (i.e. flight legs in airlines or trips in bus line or train journey) to sets of crew members, so that all activities are covered in an optimal way [Caprara *et al.* 1997-1998]. In the CSP, activities are derived from a given timetable and each activity is characterized by temporal (starting and ending time) and spatial (location) features.

CSPs in the transportation area are typically decomposed into two sub-problems: pairing construction first and crew rostering subsequently. The former is the process of generating a set of feasible duties, also called pairings, so that a given set of trips (or flight legs) is covered at the minimum cost. Afterwards, the crew rostering assigns pairings to each individual crew.

Crew scheduling and rostering have received considerable attention in the literature of the last decades. A large number of studies deal with planning crew pairing and rostering in airline, public transport and railway applications [see, among the most recent, Barnhart *et al.* 2003, Kohl and Karisch 2004, Medard and Sawhney 2007, Caprara *et al.* 2001]. The majority of the studies available propose models developed for specific fields of application, though some attempts have been made in order to build application-independent formulations [Brucker *et al.* 2011, Beasley 1998]. However, these general models perform poorly in applications requiring flexible and rapid responses, as is the case of CTs, where the number of vessels to be handled in each shift is far from certain and not well known in advance.

A complete and relatively recent review of applications, models and algorithms for the SSP in several application areas can be found in Ernst *et al.* [2004].

2.5.3 The CSP in maritime CTs

The approach characterizing the SSP in maritime CTs is different from that characterizing the SSP in others transportation fields, for two main reasons. The first reason concerns the subject of the SSP. While normally the SSP concerns travelling crew, in maritime CTs it concerns ground crew, the so-called *gangs*; as a consequence there are no defined activities to be performed with fixed starting and ending times. The second reason concerns the uncertainty of workforce demand. The development of a model for the manpower allocation necessarily requires the knowledge of the demand data concerning the jobs to be performed in the time horizon planned. In most transport sectors, demand information is a known input data straight derived from the time tables of the service, which are known in advance. In other cases, such as in CTs, demand data cannot be precisely known in advance.

As seen in the previous section, the workforce demand in terminal activities depends on the number of vessels to be served in a given day, and this information is affected by the uncertainty linked to the arrival times of vessels at the terminal. To be more precise, the arrival day of a container vessel can be considered deterministic thanks to the ETAs that every vessel periodically sends to the terminal before its arrival, whereas the precise arrival time in that day can be known with certainty only few hours ahead. We have seen in the previous section that, in order to face these difficulties, the Italian CTs have decomposed the scheduling of workers in long-term and short-term plans. Keeping in mind the decomposition technique used for solving CSPs in the airline or railway sectors, it is clear that the approach characterizing the SSP in CTs is practically the opposite: the construction of long-term schedules before and then the pairing construction. These reasons make it essential to face the SSP in maritime CTs with a different approach compared to other transportation sectors' i.e. using models tailored to the specific field.

Literature concerning the SSP in maritime CTs is quite limited, probably just because of the peculiarities of the problem addressed. In order to give a wider view of the studies dealing with the management of human resources in maritime CTs, this paragraph also includes studies concerning the general problem of HR management in CTs, even when it is not treated as a problem of staff scheduling in the strictest sense of the word.

Kim *et al.* [2004] investigated the scheduling of operators of handling equipment such as quay cranes, yard cranes and truck trailers. They called the problem addressed as *operator scheduling problem* in which every operator has to be assigned to each piece of equipment during the operating time slots scheduled for the equipment, satisfying several constraints. The operator scheduling problem was formulated and solved with a commercial software by a constraint satisfaction technique. The problem addressed is different from the traditional SSP and it arises only when the working shifts of operators have already been determined. Hence, in their problem setting, the number of workers is taken for granted and drawbacks deriving from possible workforce shortages are not addressed.

Lim *et al.* [2004] formulated a manpower allocation model as a multi-objective Vehicle Routing Problem with time windows, in which they aimed to plan the movements of operators at Singapore port. In this manpower allocation model there are three main objectives: the primary aim is minimizing the number of operators used in the fulfilment of the demand, the second aim is minimizing the travel distances, while the third objective concerns the minimization of the total travel and waiting times. Their problem is not classified as SSP and it arises only once the operational planning of workforce management has been addressed. As a result, the number of operators was supposed to be known and the impact of manpower undermanning was neglected.

Hartmann [2005] presented a general model for various scheduling problems arising in CTs. The study proposed a general model for the scheduling of resources, such as equipment or manpower. His model is not designed for a specific single application and consists of a set of jobs (or activities) that must be assigned to resources. Four different applications of the model were proposed in the study, they concern straddle carriers, automated guided vehicles, stacking cranes and reefer workers. Even in this paper we can say that the problem addressed arises when the SSP has been already performed. Manpower undermanning was not investigated.

Legato and Monaco [2004] investigated the manpower planning problem concerning dock workers who perform logistics activities related to loading or unloading operations required by arriving/departing container vessels as well as handling activities on the yard. Considering the uncertainty that characterizes the work demand in a CT and the obligation of defining working schedules covering a long time horizon (typically a month), they decomposed the manpower planning problem into monthly and daily plans, proposing mathematical programming models for both problems.

Although their formulation is the closest to our problem, they did not highlight the fundamental issue of manpower shortages, and did not consider different priorities among activities and different abilities among operators.

2.6 Case Studies

This paragraph is mainly derived from interviews and discussions with managers and personnel of the two CTs under study. Operating layout and work organisation of the two terminals are here briefly described.

2.6.1 Cagliari Transhipment Container Terminal

Cagliari transhipment CT is the second hub port in Italy for traffic volumes. It is located in Cagliari on the southern coast of Sardinia, in the middle of the West Mediterranean Sea. Its barycentric position and its short distance, only 56 NM, from the ideal route Suez-Gibraltar make this CT an attractive alternative for large container vessels sailing on the Suez-Gibraltar route.

The terminal was built in the 1980s, although handling activities started effectively only in 2003 with the entry of CICT - Cagliari International Container Terminal[6]. Until then, traffic volumes had been very low (Table 2.1). With the entry of CICT the terminal went through a period of growth rising its traffic volume to 313.938 TEUS in 2003 (+426% compared to 2002), and steadily increasing year by year until 2007 (see Table 2.1). Starting in the autumn of 2007 and for the whole of 2008, the terminal experienced a deep crisis due to the abandoning of Maersk Group, until then the main client calling at the terminal. In 2009, despite the global financial crisis, there was a recovery in the terminal throughput, mainly determined by the entry of the global carrier operator Hapag Lloyd. Since 2009 traffic volumes have remained almost constant.

Table 2.1 – Cagliari Container Throughput.

Cagliari Container Traffic [TEUs]											
Year	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**
Traffic Volume	621.536	603.236	629.340	736.984	307.527	547.336	687.657	639.049	501.194	313.938	73.657

Source: CICT.

Terminal layout at CICT

The terminal has two quays (total length 1.520 m) with seven berths of 16m of depth and allows the berthing of big containerships. The container yard has an area of 400.000 sqm which results in a capacity of 30.000 TEU. A part of the yard (936 slots) is reserved for reefer containers. The handling capacity of the terminal is estimated in

6 CICT is a terminal operator of the ContShip Italia Group – Eurokai Group.

1.200.000 TEUs per year. The main technical data about CICT are summarised in Table 2.2.

Table 2.2 – CICT - Technical Data.

CICT – Technical data		
Infrastructure		
Berth length	[m]	1.520
Draft	[m]	16
Yard area	[sqm]	400.000
Yard capacity	[TEUs]	30.000
Reefer slots	[slot]	936
Equipment		
Quay cranes		7
Mobile cranes		1
Rubber Tired Gantry cranes		17
Truck Trailers		28
Reach stackers		5
Front loaders		8
Nominal capacity		
Handling capacity	[TEUs/year]	1.200.000

Source: CICT.

Operating layout at CICT

The operating system used at CICT is the Indirect Transfer System based on RTG (Rubber Tyred Gantry) cranes. Containers are unloaded from vessels by means of 7 Ship-to-shore quay cranes, which place boxes on 28 truck trailer units that transfer them to the storage area where 17 RTGs, which moves on rubber-tyred wheels, stack them in blocks. A representation of a transhipment CT operated by RTGs is provided in Figure 2.3.

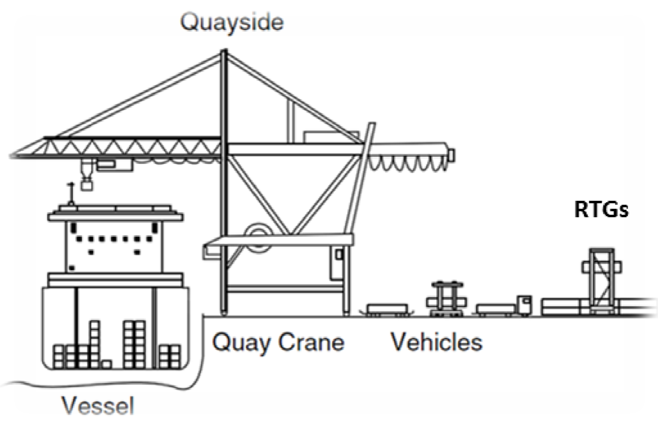

Figure 2.3 – Layout of a Transhipment CT operated by RTGs.
Source Vis and de Koster [2003].

Work organisation at CICT

The working day at CICT is organised into four shifts of six hour each[7]. The starting and ending times of each shift are reported in Table 2.3.

Table 2.3 – Daily shifts.

Shift	Starting and Ending Times
1	01:00 – 07:00
2	07:00 – 13:00
3	13:00 – 19:00
4	19:00 – 01:00

Source: CICT.

Handling operations are performed by teams of workers, also called working gangs. There are two types of gangs: vessel gangs and housekeeping ones. The standard vessel gang at CICT is made up of 1 quay craner, 2 yard craners and 3/4 truck trailer drivers. This configuration is the most used one, but if necessary it can be changed to fit better some particular activities. In each gang, driving operators are supported by ground workers, in detail: 1 checker, 1 deckman and 3/5 lashers per gang. Housekeeping gangs have the same configuration but do not provide quay cranes.

Nowadays, around 90 driving operators are in stable service at CICT terminal. The 90 dockworkers can perform different tasks according to their professional level. A system of standardized certifications defines the professional growth of each operator working at the terminal. Tasks follow a top-down structure whereby workers can perform only their main task (the high level task for which they are qualified) and tasks of lower level but not higher level tasks. The quay craner is the top level task, followed by the yard craner and the truck trailer driver.

Temporary workers may be called at the terminal if internal manpower is not sufficient to cover the work demand of the day. Currently only two external companies[8] are authorized to provide temporary work at CICT terminal. Temporary workers, also called *external workers*, can perform only lashing operations onboard and driving tasks of the lowest level (truck trailer) in the terminal yard.

[7] Starting in 2012, the working day at CICT has been split into three shifts of eight hours each (23:00-07:00; 07:00-15:00, 15:00-23:00). Contracts on handling activities with shipping companies are still made on the basis of the traditional four shifts.
[8] ITERC (*Impresa TERminalista Cagliari*) and CLP (*Compagnia dei Lavoratori Portuali – Dockers' Companies*).

The manpower planning is organised according to the two levels described in the paragraph 2.4. According to second level agreements, shifts of flexible and external workers must be communicated with a 24-hour notice. In accordance with the National labour regulations, a rest of minimum 11 hours must be guaranteed between two consecutive working shifts. No differences exist between day and night shifts in respect to the minimum rest period. The use of overtime at CICT is limited because of its high cost; on average it costs 30 per cent more than regular work.

Currently, the planning of the workforce at CICT is performed by terminal planners on the basis of their experience. No advanced tools are available at this time to support this complex decision process.

2.6.2 Gioia Tauro Transhipment Container Terminal

Gioia Tauro Container Terminal is the main Italian CT and one of the most important Mediterranean transhipment CTs for traffic volumes. The terminal is managed by MCT - MedCenter Container Terminal[9], which has a fifty-year concession for port services. The terminal, hereafter MCT, is located in the west coast of the South of Italy and, because of its barycentric position in the Mediterranean basin, it is attractive for vessels sailing on the Suez-Gibraltar route[10]. Originally designed as industrial port, it was converted to a multipurpose port at the end of 1970s when the world container traffic was experiencing its large increase, becoming in brief time the most important hub terminal operating in the Mediterranean sea [Della Corte 2002].

After a period of growth, difficulties for MCT started at the end of 2008 when the effects of the global financial crisis were amplified by the abandon operated by the Grand Alliance carriers and the resulting drop in volumes needed to be handled (see Table 2.4). The first action taken by MCT to face the crisis was cutting labour cost: ordinary redundancy was introduced, the majority of workers involved were yard operators.

The recovery began in 2012 when MCT with Contship sold 50% of the capital to TIL (Terminal Investment Ltd), a company that has close links with MSC[11] (Mediterranean Shipping Company), the world's second largest shipping line[12] . The entry of TIL has led to a substantial market recovery, although the labour situation for MCT dockworkers still remains difficult (at the moment of our interviews in 2012, 496 dock workers were under

9 MCT is a terminal operator of the Contship Italia Group – Eurokay Group.
10 Gioia Tauro is distanced about 73 NM from the main East-West route.
11 MSC is a privately owned shipping line founded in 1970, which in brief time has become one of the leading global shipping lines.
12 alphaliner.com, 2013.

extraordinary layoff). MCT is now equally owned by APM terminals, Contship Italia and TIL.

Table 2.4 – Gioia Tauro Throughput.

Gioia Tauro Container Traffic [TEUs]									
Year	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**
Traffic Volume	2.721.104	2.305.000	2.852.264	2.857.440	3.467.824	3.445.000	2.938.200	3.161.000	3.261.034

Source: MCT.

Terminal layout at MCT

The total berth length is 3.391 m and the quay draft ranges between 16 and 18 m allowing the berthing of the big Super-Post-Panamax vessels. The container yard has an area of 1.600.000 m^2 resulting in a capacity of 75.000 TEUs. A part of the yard (2.300 slots) is reserved for reefer containers. The handling capacity of MCT is estimated at 4.000.000 TEUs per year.

Main technical characteristics of MCT are summarised in Table 2.5.

Table 2.5 – MCT - Technical Data.

MCT – Technical data		
Infrastructure		
Berth length	[m]	1.391
Draft	[m]	16 – 18
Yard area	[sqm]	1.600.000
Yard capacity	[TEUs]	75.000
Reefer slots	[slot]	2.300
Equipment		
Quay cranes		22
Mobile cranes		2
Straddle carriers		125
Reach stackers		13
Nominal capacity		
Handling capacity	[TEUs/year]	4.000.000

Source: MCT.

Operating layout at MCT

The operating system used at MCT is the Direct Transfer System based on Straddle Carriers (SC). A representation of a transhipment CT operated by RTGs is provided in Figure 2.4. Containers are handled from/onto vessels through 22 quay cranes, four of which are able to operate on Super-Post-Panamax vessels with a loading capacity of 10.000/12.000 TEUs. 125 SCs are used to transfer containers from the yard to the quay and vice versa, whereas 13 reach stackers are used for handling empty containers.

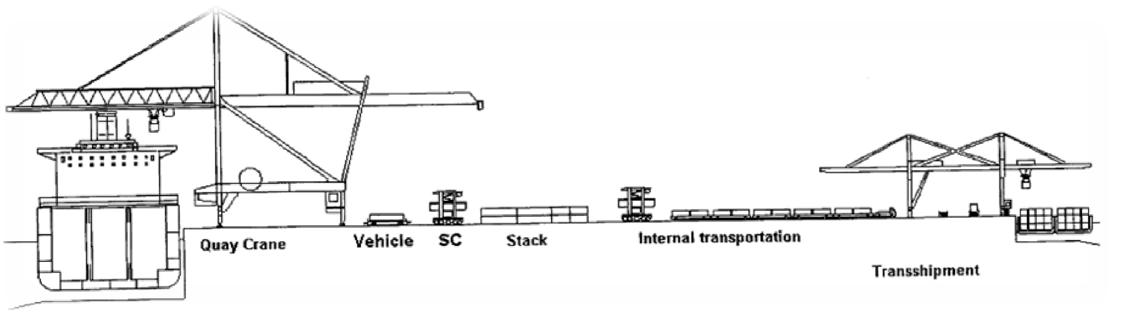

Figure 2.4 – Layout of a Transhipment CT operated by SCs.
Source: Steenken *et al.* [2004].

Work organisation at MCT

The working day at MCT is organised into four shifts of six hours each. Starting and ending times of shifts follow the same timetable as described for CICT (Table 2.3). Handling operations at MCT are performed by vessel and housekeeping gangs. The standard vessel gang at MCT is made up of 1 quay craner and 3/4 straddle carrier drivers. If necessary, the number of SC drivers can be increased to fit better some particular activities. In each gang, driving operators are supported by ground workers, typically 1 checker, 1 deck-man and 3/5 lashers per gang.

Currently, around 550 dockworkers are in service at MCT terminal; more than half of them can perform driving tasks (quay cranes and straddle carriers). As in the case of CICT, MCT workers can perform different tasks according to their professional level certified by a system of qualifications. Tasks follow a top-down structure whereby workers can perform only their main task (the high level task for which they are qualified) and tasks of lower level but not higher level tasks. The quay craner is the top level task, followed by the straddle carrier driver, ground tasks are of lower level.

Temporary workers may be called at the terminal if internal manpower is not sufficient to cover the work demand of the day. Currently, lashing operations at MCT are almost completely outsourced (90% of lashing is performed by external firms). In addition to lashing operations onboard, external workers can perform tasks of the lowest level at the terminal yard.

Manpower planning is organised according to the two levels described in paragraph 2.4. According to second level agreements, shifts of flexible and external workers must be communicated with a 24 hour-notice.

If needed, it is possible to resort to overtime by recalling workers at rest or using double shifts[13]. It should be noted that although double shifts are permitted they are usually avoided. Several reasons make double shifts unattractive for terminal operators: workers cannot perform driving tasks in their second shifts, a 45-minute rest must be guaranteed between the first and the second shift, workers performances decrease significantly in the second shift. Double shifts cost as much as the overtime, i.e. 30 per cent more than regular work.

In accordance with the National labour regulations, a rest of minimum 11 hours must be guaranteed between two consecutive working shifts (double shifts are an exception). No differences are made between day and night shifts in respect to the minimum rest period.

According to second level agreements, a number of additional constraints concerning shifts sequence and task executable exist: the shift-sequence 4-3-2-1 is prohibited, craners can perform maximum 8 shifts as quay craners every 12 shifts worked, while SC divers can perform maximum 6 shifts as SC drivers every 8 shifts worked; the rest of the shifts they can perform only ground tasks.

Currently the management of manpower at MCT is performed by terminal planners with the support of the "Sipario" software. The software is calibrated on the specific need of MCT and it is based on the optimisation model developed by Legato and Monaco [2004]. Manpower shortages as well as different priorities of activities and different abilities of workers are not taken into account. On the basis of their experience, planners can subsequently correct the decisions taken by the software.

2.7 Conclusion

In the competitive environment of CTs, an optimal manpower management is a priority in pursuing a policy of reducing operating costs and minimizing vessel turnaround times.

Managing HR in CTs is a very complex issue: terminals have to be manned 24 hours a day, the interaction between different workers needs to be taken into account and operations

[13] MCT workers can perform maximum 23 double shifts per year.

are intrinsically uncertain. Moreover, in manned CTs labour represents the most relevant cost item with a percentage of incidence on total operating costs ranging from 50 to 75 per cent. An optimal management of the workforce is a priority for terminal operators, which not surprisingly have begun to show attention for innovative analytical tools to support their complex decision-making processes.

In this chapter we have analysed the manpower management problem as it arises in Italian CTs. In particular, we have focused on two important transhipment CTs: CICT in Cagliari and MCT in Gioia Tauro. We have seen that the contrast between the impossibility to determine in advance and with sufficient precision the labour demand that will characterize the next months of activity, and the obligation established by contractual clauses to plan working shifts a number of months ahead, has led Italian CTs to decompose the planning of the workforce into two moments: long-term and short-term. The first one determines a sequence of workdays and rest days for each worker only on the basis of contractual agreements, whereas the second one is a refinement of the first one and it is performed when demand data is more precise. The major risk at this stage is the occurrence of manpower shortages due to under-estimated demand. Manpower shortage may result in longer handling times and unnecessary costs for both the vessel and the port. Actually, an over-estimation should also be avoided because it may not be convenient from an economic point of view and it could result in manpower shortages in the following working shifts.

In our research we are going to focus on the short-term plan which deserves special attention because it inherits some unchangeable decisions from the long term plan, it involves the use of terminal workers considering the real work demand and it leads to final estimations of costs and benefits deriving from optimisation processes.

Looking at the existing literature, there seems to be a big difference between the approach used for staff scheduling in CTs and the one used in other transportation fields; there are two main reasons: (1) while normally concerning travelling crew, staff scheduling in maritime CTs concerns ground crew, as a consequence there are no defined activities to be performed with fixed starting and ending times; (2) the approach characterizing the staff scheduling in CTs is the opposite of that used in other transportation sectors - construction of long-term schedules before and then pairing construction. The peculiarities of the problem addressed do not allow the application of traditional methods but require specific approaches tailored to the specific case. Despite its importance, very few studies have so far addressed the general problem of manpower management in CTs. Among these studies only one faced the specific problem of manpower scheduling in CT activities, while no studies have investigated the fundamental issue of shortages.

The main aim of this chapter was to identify the features of the HR management in CTs and to investigate the main gaps existing in literature. On the basis of what has been discussed so far, we can proceed to the next chapter so as to discuss in detail our optimisation model for the daily allocation of HR in CTs.

CHAPTER 3*

An Optimisation Model for the Optimal Daily Allocation of Human Resources in Container Terminals

3.1 Introduction

The daily management of HR in CTs is highly complex due to the numerous variables and constraints involved and to the uncertainty on demand data. Leaving aside the problem of uncertainty and supposing that planning horizons are quite short, there would still be the problem of assigning a number of operators with diverse abilities, performances and costs to shifts and activities with different priorities and different levels of difficulty.

Nowadays, the majority of planners take these decisions mainly on the basis of their experience through a manual process that is costly in terms of time and effort, but with results that are not always satisfactory. Not surprisingly, in the last decades, terminal operators have begun to extend their interest in innovative analytical tools that can support planners in the complex decision making processes on terminal operations and their planning [Vis and Koster 2003] .

As discussed in the previous chapter, when we began our research, there was a lack of literature on HRA in the specific context of port activities. Very few studies have faced the specific problem of the staff scheduling in maritime ports [Monaco *et al.,* 2009;

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* **A preliminary version of this chapter appeared as Fancello *et al.* (2011).**

Legato and Monaco, 2004]. Moreover this specific problem has been faced so far by means of optimisation models in which the fundamental issue of shortages has been totally neglected. All existing models assume to have sufficient operators for the workload of CTs and do not compute workforce shortages. In the attempt to overcome this gap, we have modelled shortages as apposite decision variables and have developed a new optimisation model for the daily management of dockworkers that integrates undermanning personnel with the allocation of workers to shifts, tasks and activities, while taking into account the long-term planning and further operating requirements. Our optimisation model has been developed in close cooperation with CICT and MCT.

This chapter has four main goals:

- provide the reader with the specific terminology used in this field;
- formulate an optimisation model for the daily allocation of dockworkers in CTs;
- show that the proposed model is an effective tool to support the decision making process of CTs by means of a numerical experimentation derived from real-world data;
- show that existing solvers can be successfully adopted in the CT management, because they can determine optimal decisions in realistic size instances within the time limits imposed by planning operations.

The chapter is then structured as follows: section 2 defines our problem setting while discussing the main elements and decisions characterizing the operational allocation of HRs to shifts, tasks and activities in CTs. Features of the daily HRAP are modelled by an Integer Linear Programming Model, which is presented in section 3. Section 4 illustrates a numerical application of our optimisation model tested with data directly provided by CICT. Finally, the last section presents some concluding remarks and explains how this chapter is a significant contribution to current literature concerning this field of study.

3.2 Problem description

This paragraph provides a description of the HR allocation problem in CTs and of its mathematical model. It also provides the reader with the terminology and key concepts found in the study.

As previously mentioned, decisions concerning the daily allocation of HRs in CTs must take into account a large array of information, such as specific work rules, particular operator skills, as well as specific relations with the operating environment: long-term planning constraints, different priorities for activities, contracts with vessel operators, etc. It is worth noting that features and constraints of the HR management problem in CTs may slightly vary among ports of the same country depending on the specific *modus operandi* of each terminal. Moreover, differences may occur among terminals of different countries where the management of human resources is affected by diverse policies and regulatory requirements in the area of port labour [Van Hooydonk, 2013].

We focus on the Italian case, in particular, we analyse the two main Italian transhipment CTs: CICT and MCT. Internships at the two terminals and several meetings with terminal experts have allowed us to acquire a good knowledge of the problem and to define the main features and constraints characterizing the HRA in these terminals. Our problem setting is illustrated below.

The daily allocation of HR in CTs typically involves two classes of workers: *internal workers* of CTs and *external ones*. External workers are recruited outside of the dock workers pool and can be employed when internal operators are in short supply[14]. The number of external workers is normally limited and they can perform only low level tasks, thus shortages may sometimes occur. Since transhipment maritime CTs cannot afford to pay penalties due to delays in the service of vessels, they can resort to operators working overtime and having days off according to the long-term planning, as long as personnel undermanning is detected timely.

Operators can perform one or more tasks according to their qualification level. Highly-skilled operators can perform high level tasks and, when necessary, lower level ones while less qualified operators can perform only low level tasks. For example, in a CT where handling activities are based on the indirect transfer system (quay craner, yard craner and truck trailer driver), the quay craner is the top-level driving task because he can also perform any other driving task, whilst a yard craner can also drive a truck trailer, but a truck trailer driver can perform his task only. In this top-down skill structure, operators have their own main task for which they must be paid, even if they are assigned to a lower-level one, whereas they cannot perform upper lever tasks.

Two main types of activities are performed in transhipment maritime CTs: vessel activities, i.e. loading/discharging operations, and housekeeping ones. A vessel activity is a sequence of handling operations on containers, which must be loaded onto and

14 In some CTs a minimum number of external workers have to be employed every day due to specific agreements between the terminal and external firms that provide temporary port labour.

discharged from vessels. A housekeeping activity is a sequence of handling operations on containers, which must be moved in different parts of the CT yard.

Activities are performed by gangs, which are teams of workers trained for the different tasks. Operations on vessels are performed by quay craners, yard craners and truck trailer drivers (or straddle carriers, depending on the terminal operating layout), whereas housekeeping activities do not involve quay craners. Some activities have high priorities, while others do not and they can be postponed. Generally speaking, vessel operations take precedence over housekeeping ones. Mother vessels have the highest priority and must be served on time, due to relevant penalties negotiated between shipping companies and transhipment maritime CTs on potential operation delays.

All activities and all tasks are performed by dockworkers during shifts. The daily plan is required to take into account shifts already decided in the long-term plan, which provides each operator with a sequence of workdays and off-days. The so-called *fixed operators* are already assigned to shifts, i.e. they know the starting and ending time of their work from the long-term plan. Moreover, in some CTs they can be employed in additional shifts if a proper number of rest shifts is guaranteed[15]. The so-called *flexible operators* are already assigned to a specific day, i.e. they know that they will work in that day, but their shift on that day is unspecified in the long-term plan. They can be assigned by the daily planning if requested by terminal workloads. According to work rules, flexible operators must be informed of their shift 24 hours before the work day in which they will be employed. Even in the case of flexible operators, a minimum number of rest shifts must be guaranteed between any consecutive pair of working shifts. In some terminals, a larger rest time must be assigned after a nightly shift.

The work demand of the day can be estimated in terms of the workers required to perform tasks and activities during shifts. Since operations are performed by gangs, the work demand can be computed as the number of gangs multiplied by the number of workers in each gang. One could note that a better way to estimate the work demand of the day would be by using the number of containers to be handled instead of the number of gangs. Actually, in the interviews, terminal experts stated that the use of the number of containers as demand data may be misleading as it may not reflect the real need of manpower, which, instead, is calculated by operating offices on the basis of various

[15] Starting from 2012, the working day at CICT has been divided into three shifts of eight hours each and operators can perform only one shift per day, whereas at MCT, where the working day is divided into four shifts of six hours each, operators can perform more than one shift per day, if rest periods among working shifts are guaranteed.

constraints: availability of quay cranes, agreements with shipping lines, load configuration on the vessel, quay configuration, etc.

The objective of the daily plan is to assign internal and external workers to shifts, tasks and activities at the lowest operating cost, as well as to minimize operators' shortages. Evaluating costs of internal operators is not a straightforward process, because they do not depend only on the wages defined in work contracts. For example, let us consider two workers with identical wages according to work contracts. If one of them is more efficient, he leads to lower operating costs from the point of view of the CT. Moreover, the most efficient operators should be assigned to the most profitable and complex activities.

It is worth noting that external workers are added to provide additional manpower, but no individual features characterize their costs. According to work contracts, overtime costs are higher than others and, hence, they should not be used unless absolutely necessary. Overtime costs depend on the level of the task (high level tasks cost more than low level ones), as well as on activities (for instance, services on vessels generate higher costs than housekeeping operations) and shifts (typically overtime costs are higher at night).

3.3 The optimisation model

This paragraph presents an optimisation model for the daily allocation of human resources involved in driving tasks in transhipment maritime CTs. The model has been specified on the basis of the features of the problem described in the previous paragraph.

Let N be the set of internal operators at hand. They can be employed on a number of shifts in set J and, according to work rules, a rest of $r(j)$ shifts must be guaranteed after a duty. The number $|J|$ of shifts defines the length of the planning horizon. Let K be the set of driving tasks (quay craner, yard craner, truck trailer drivers, etc.) and Z the set of activities to be performed. Activities are sets of vessel and housekeeping operations to be performed. Let S be the set of vessel operations and H the set of housekeeping activities, such that $Z = S \cup H$.

Three types of variables are defined:

- x_{ijkz} is a binary variable, which takes value 1 if worker $i \in N$ is assigned to shift $j \in J$, task $k \in K$ and activity $z \in Z$, 0 otherwise. If i is a worker in fixed service, we are required to determine only the task $k \in K$ and his activity $z \in Z$, else, if i is a worker in flexible service in the planned day, we must decide his shift $j \in J$ as well.
- v_{jkz} is an integer non-negative variable representing the number of external workers assigned to shift $j \in J$, task $k \in K$ and activity $z \in Z$. Let also w be the maximum number of external workers employable by the terminal in the planned day.
- u_{jkz} is an integer non-negative variable representing the personnel shortage in shift $j \in J$, task $k \in K$ and activity $z \in Z$.

The work demand is estimated in terms of workers assigned to tasks and activities during shifts. Since operations are performed by teams of workers, in this paper the work demand is expressed in terms of number of teams multiplied by the number of workers in each team. Therefore, let ns_{jk} be the number of workers in a vessel team performing task $k \in K$ in shift $j \in J$ and let s_{jz} be the number of teams requested to perform vessel activity $z \in S$ in shift $j \in J$. Work demand $ns_{jk} \cdot s_{jz}$ in shift $j \in J$, task $k \in K$ and activity $z \in Z$ can be met by internal operators and external ones. However, sometimes workers are not sufficient and personnel shortage must be computed for each shift $j \in J$, task $k \in K$ and activity $z \in Z$. Therefore, the requirement of work demand fulfilment for vessel operations can be indicated as follows:

$$\sum_{i \in N} x_{ijkz} + v_{jkz} + u_{jkz} = ns_{jk} \cdot s_{jz} \qquad \forall j \in J, \forall z \in S, \forall k \in K \qquad (1)$$

When a task $\bar{k} \in K$ cannot be performed by external operators, $v_{j\bar{k}z}$ takes value zero. A similar constraint is adopted for housekeeping operations. Therefore let nh_{jk} be the number of workers in a housekeeping team performing task $k \in K$ in shift $j \in J$, and let h_{jz} be the number of housekeeping teams requested in activity $z \in H$ and shift $j \in J$. Work demand $nh_{jk} \cdot h_{jz}$ in shift $j \in J$, task $k \in K$ and activity $z \in Z$ can be met by internal operators, external ones or personnel shortfall u_{jkz} must be computed:

$$\sum_{i \in N} x_{ijkz} + v_{jkz} + u_{jkz} = nh_{jk} \cdot h_{jz} \qquad \forall j \in J, \forall z \in H, \forall k \in K \qquad (2)$$

Let $N_j \subseteq N$ be the set of fixed workers already assigned to shift $j \in J$ in the long-term plan. Their assignment cannot be changed at the operational planning level. However, these operators can also be assigned to additional shifts during the planning horizon to face unexpected work demand. In order to model this constraint, let y_{ij} be a coefficient, which takes value 1 if operator $i \in N$ is already assigned by the long-term plan to shift $j \in J$, i.e. if $i \in N_j$, 0 otherwise. To consider the long-term plan and employ fixed operators on additional shifts, constraint (3) is formulated as follows:

$$\sum_{k \in K} \sum_{z \in Z} x_{ijkz} \geq y_{ij} \qquad \forall i \in N_j, \forall j \in J \qquad (3)$$

The possibility of the assignment of workers to more than one shift in the day planned should take into account rest shifts for each operator. According to work rules, an operator $i \in N$ cannot be assigned for $r(j)$ consecutive shifts after his work in a shift $j \in J$. Then, if operator $i \in N$ is assigned to task $\mathrm{k} \in \mathrm{K}$ and activity $\mathrm{z} \in \mathrm{Z}$ in shift $j \in J$, he cannot work from shift $j + 1$ to shift $j + r(j)$, i.e.:

$$\sum_{k \in K} \sum_{z \in Z} (x_{ijkz} + \sum_{\rho=1}^{r(j)} x_{i(j+\rho)kz}) \leq 1 \qquad \forall i \in N, \forall j \in 1 \ldots (|J| - r(j)) \qquad (4)$$

In terminals where workers can perform no more than one shift per day the constraint (4) can be written more simply as:

$$\sum_{j \in J} \sum_{k \in K} \sum_{z \in Z} x_{ijkz} \leq 1 \qquad \forall i \in N \qquad (4.1)$$

The number of external sub-contracted workers is limited:

$$\sum_{j \in J} \sum_{k \in K} \sum_{z \in Z} v_{jkz} \leq w \qquad (5)$$

In what follows, major attention is paid to the costs of variables x_{ijkz}, v_{jkz} and u_{jkz}. The unitary cost c_{ik} of internal operator $i \in N$ depends on his main task $k(i) \in K$: he must be paid for his main task $k(i) \in K$ and cannot be assigned to upper level tasks $\bar{k}(i) \in K$, whereas he can be assigned to lower level tasks $\tilde{k}(i) \in K$. We denote by c_k the cost of an operator with main task $k \in K$ and by $c_{k(i)}$ the cost of task $k \in K$ assigned to operator $i \in N$. The cost of internal operator $i \in N$ performing task $k \in K$ can be denoted by c_{ik} and defined as follows:

$$c_{ik} = \begin{cases} c_k & if\ k = k(i) \\ c_{k(i)} + \left(c_k - c_{k(i)}\right) = c_k & if\ k = \tilde{k}(i) \\ M & if\ k = \bar{k}(i) \end{cases} \tag{6}$$

where M is sufficiently larger than all real costs in the model [Legato and Monaco 2004]. However, the cost of internal operators should also depend on additional parameters, such as the activity $z \in Z$ in which the operator is employed. In fact, different levels of profitability exist between activities, some operators are more efficient than others and they should be tasked with the most profitable activities. Moreover, the productivity of internal operator $i \in N$ also depends on shift $j \in J$ [Fancello *et al.* 2008]. Therefore, we denote by c_{ijkz} the unitary cost of internal operator $i \in N$ working at shift $j \in J$ in task k ∈ K and activity z ∈ Z. We define by p_{ijkz} the productivity index for operator $i \in N$ working at shift $j \in J$ in task $k \in K$ on activity $z \in Z$: the higher p_{ijkz}, the more efficient operator $i \in N$ and the lower c_{ijkz}. Moreover, we define the profitability of activity $z \in Z$ by index g_z: the higher g_z, the more profitable activity $z \in Z$ and the lower c_{ijkz}. Since an activity may be performed under easy or difficult operating environments (for instance meteorological conditions), we also define the coefficient a_z measuring the complexity of activity $z \in Z$: the higher a_z, the easier activity $z \in Z$ and the lower c_{ijkz}. According to the above relations, in this study the following expression is proposed for c_{ijkz}:

$$c_{ijkz} = \frac{c_{ik}}{p_{ijkz} \cdot a_z \cdot g_z} \tag{7}$$

Finally, let b_{jkz} be the unitary cost of an external operator assigned to task $k \in K$ and activity $z \in Z$ in shift $j \in J$ and let d_{jkz} be the unitary cost generated by the shortage of an operator in shift $j \in J$, task $k \in K$ and activity $z \in Z$. Generally speaking, d_{jkz} are larger than c_{ijkz} and b_{jkz} in order to limit overtimes.

We must minimize costs generated by the assignment of internal and external operators, as well as manpower shortages:

$$\min \sum_{i \in N} \sum_{j \in J} \sum_{k \in K} \sum_{z \in Z} c_{ijkz} \cdot x_{ijkz} + \sum_{j \in J} \sum_{k \in K} \sum_{z \in Z} b_{jkz} \cdot v_{jkz} + \sum_{j \in J} \sum_{k \in K} \sum_{z \in Z} d_{jkz} \cdot u_{jkz} \qquad (8)$$

The whole notation used in the model is illustrated in Table 3.1.

Table 3.1 – Parameters.

	Symbol	*Description*
Sets	J	Shifts
	K	Tasks
	S	Ships to be handled
	H	Housekeeping operations
	Z	Activities to be performed (S U H)
	N	Internal workers
	N_j	Internal workers already assigned to shift $j \in J$ by the long-term plan ($N_j \subseteq N$)
Parameters	$ns_{j,k}$	Number of workers in a vessel gang performing task $k \in K$ in shift $j \in J$.
	$nh_{j,k}$	Number of workers in a housekeeping gang performing task $k \in K$ in shift $j \in J$.
	$s_{j,z}$	Number of gangs required to perform vessel activity $z \in S$ in shift $j \in J$.
	$h_{j,z}$	Number of gangs required to perform housekeeping activity $z \in H$ in shift $j \in J$.
	y_{ij}	$y_{ij} = 1$ if operator $i \in N_j$, 0 otherwise.
	$\|J\|$	Planning horizon length.
	$r(j)$	Number of off-duty shifts required after shift $j \in J$.
	w	Maximum number of available external workers.
	c_{ik}	Unitary cost of internal operator $i \in N$ on his main task $k(i) \in K$.
	c_{ijkz}	Unitary cost of internal operator $i \in N$ in shift $j \in J$, task $k \in K$ and activity $z \in Z$.
	p_{ijkz}	Productivity index of operator $i \in N$ working at shift $j \in J$ in task $k \in K$, activity $z \in Z$.
	a_z	Complexity index of activity $z \in Z$.
	g_z	Profitability index of activity $z \in Z$.
	b_{jkz}	Unitary cost of an external operator in shift $j \in J$, task $k \in K$ and activity $z \in Z$.
	d_{jkz}	Unitary cost of operator shortfall in shift $j \in J$, task $k \in K$ and activity $z \in Z$.
Decision Variables	x_{ijkz}	Binary variable taking value 1 if internal worker $i \in N$ is assigned to shift $j \in J$, task $k \in K$ and activity $z \in Z$, 0 otherwise.
	v_{jkz}	Number of external workers assigned to shift $j \in J$, task $k \in K$ and activity $z \in Z$.
	u_{jkz}	Number of workers in shortage in shift $j \in J$, task $k \in K$ and activity $z \in Z$.

Source: author.

3.4 A numerical experimentation on CICT

In this section, we aim at verifying the capability of the proposed optimisation model to solve realistic world instances. Numerical tests are carried out to evaluate the effective ability of the model in finding the optimal daily allocation of dockworkers to shifts, tasks and activities and, therefore, in supporting the decision making process of terminal planners.

There are three typical situations that may occur in the daily management of HR in CTs:

1. Demand = Supply: number of available workers is equal to the work demand of the day;
2. Demand < Supply: number of available workers is larger than the work demand of the day;
3. Demand > Supply: number of available workers is lower than the work demand of the day.

The model is tested in each of these typical situations. All data used to generate the problem instances during the testing phase have been realistically derived from typical working days in the two CTs under analysis. The optimisation model has been solved by the freeware solver GLPK[16] and the commercial solver Cplex 11.1[17], that have been able to determine the optimal solution for all realistic size instances tested in a very short time (less than 1s for all instances), which is far suitable for the operating requirements of transhipment CTs. Since providing a complete overview of all tests carried can be a long and unnecessary process for the purpose of the analysis, in order to facilitate the reader in understanding how the model works, we illustrate in detail a sample case. The problem instance used in this test has been generated considering the most problematic situation that may occur in the planned day, i.e. work demand exceeding manpower supply (see Chapter 2).

Demand and supply data have been provided by terminal experts of CICT. Furthermore, the operating layout of CICT has been used to set the value of the application parameters:

- the working day is divided into 3 shifts of 8 hours each;
- 95 internal operators are available in the day, 85 are in fixed service while 10 are in flexible service[18]. The set of internal operators is taken for granted by the

[16] GLPK Package, 4.39, 2009.

[17] ILOG CPLEX, 11.1, 2008.

[18] According current labour regulations about 10% of the available workers can be in flexible service every day (see Chapter 6).

terminal, as well as their costs, main tasks and shifts according to the long-term plan;

- 15 external workers are available in the day; their unitary cost is taken for granted by the terminal. These workers are supposed to perform truck trailer driving tasks only;
- the vessel gang is made up of 1 quay craner, 2 yard craners and 3 truck trailer drivers while the housekeeping gang has 2 yard craners and 3 truck trailer drivers[19];
- the cost of shortages for the different tasks is supposed to be twice the average hourly cost of each task.
- the productivity index p_{ijkz} is taken from the terminal's historical data;
- the priority g_z of vessel operations is supposed to be twice the housekeeping priority;
- the index of activity complexity a_z is supposed to be constant in this application.

The detail of the supply data used in this application is shown in Appendix 1.

The model has been implemented by GNU MathProg modelling language. Instances have been solved by both the freeware solver GLPK 4.39, and the commercial solver Cplex 11.1, running on a PC with a 3.00 Ghz processor and 16 Gb of memory.

To illustrate work demand data for the problem instance, we refer to Table 3.2 and Table 3.3, in which each column represents a shift. In Table 3.2 the first line is denoted by VG and represents the requested number of gangs to perform vessel activities. The second line is denoted by HG and shows the number of gangs requested for housekeeping activities at each shift. For example, 6 vessel gangs and 1 housekeeping gang are requested to work at shift 3.

Table 3.2 - Requested number of gangs in *Day 1*.

Day 1	*Shift 1*	*Shift 2*	*Shift 3*
VG – Vessel Gangs	6	5	6
HG – Housekeeping Gangs	1	1	1

Source: author.

[19] We propose in this experimentation a specific configuration of gangs, which is taken from the port of the case. However, the model is general and can be initialized with all possible gang configurations (for instance, 4 or 5 truck trailers instead of 3).

Table 3.3 shows the same work demand as Table 3.2 in terms of number of operators for each task and shift. Furthermore, for each shift we distinguish between vessel and housekeeping gangs, denoted by VG and HG respectively. For instance at shift 3, 12 yard craners must be employed to serve vessels and 2 for housekeeping. Since quay craners are not involved in housekeeping activities, their demand is denoted by "-". A total of 117 driving operators are requested in the planned day.

Table 3.3 - Requested number of operators in *Day 1*.

Day 1	*Shift 1*		*Shift 2*		*Shift 3*	
	VG	**HG**	**VG**	**HG**	**VG**	**HG**
Quay craners	6	-	5	-	6	-
Yard craners	12	2	10	2	12	2
Truck trailer drivers	18	3	15	3	18	3

Source: author.

Data in Table 3.2 and Table 3.3 are used to generate our instance, which is called *Day 1*. *Day 1* is characterized by a demand of 117 workers and a manpower supply of 110 workers (95 internal workers and 15 external workers). As the operating configuration with three working shifts per day does not allow the employ of workers for more than one shift during the planned day, 7 workers are missing to exactly fulfil the total demand of the day in question.

To illustrate decisions taken by our optimisation model, we refer to Table 3.4, in which each column represents a shift and for each task lines indicate whether the work demand is met by internal operators, external ones or whether there is a shortage. As before, columns represent shifts and are divided into vessel and housekeeping gangs, which are denoted by VG and HG respectively. For instance, according to the Table 3.3, the total work demand of truck trailer drivers at shift 3 was 21 (18 for vessels and 3 for housekeeping). The demand of truck trailer drivers at shift 3 is satisfied by 11 internal operators deployed on vessel gangs, 7 external operators deployed on vessel gangs and 3 external operators deployed on housekeeping gangs.

Detail of the allocation (shift, task, and activity) for each worker is shown in Appendix 1.

These results show that the model correctly assigns all the available internal and external workers while reports 7 manpower shortages. It is worth noting that reported shortages involve only low level task which can be easily rearranged by additional terminal workers, who can be deployed in overtime shifts. The ability to correct manpower shortages in a timely fashion is a key factor for the overall productivity of CTs.

Table 3.4 - Assignment of operators in instance *Day 1*.

Day 1		*Shift 1* VG	*Shift 1* HG	*Shift 2* VG	*Shift 2* HG	*Shift 3* VG	*Shift 3* HG
Internal Operators	**Quay craners**	6	-	5	-	6	-
	Yard craners	12	2	10	2	12	2
	Truck trailer drivers	12	0	15	0	11	0
External Operators	**Truck trailer drivers**	4	1	0	0	7	3
Operator Shortages	**Quay craners**	0	-	0	-	0	-
	Yard craners	0	0	0	0	0	0
	Truck trailer drivers	2	2	0	3	0	0

Source: author.

Before concluding the paragraph, we aim to illustrate the effectiveness of solvers GLPK 4.39 and Cplex 11.1 to solve the proposed model. The first solver uses a branch-and-bound method, whereas Cplex uses a branch-and-cut algorithm improving implicit enumeration algorithms by a number of general purpose cuts[20]. The computational tests are shown in Table 3.5. The second and the third columns report the number of variables and constraints, while the last 4 columns show the objective function and CPU time for both solvers.

Table 3.5 - Computational performances.

Instance	Number of variables	Number of constraints	Objective Function *GLPK*	Objective Function *Cplex*	CPU Time (s) *GLPK*	CPU Time (s) *Cplex*
Day 1	3777	745	2185.5	2185.5	0.05	0.03

Source: author.

3.5 Conclusion

The optimal management of HRs is a major issue for CTs. In particular, the daily planning of workforce deserves specific attention, because it not only determines the final system cost incurred by workforce management but it also affects the CT ability to achieve high levels of productivity and to provide high quality services to shipping

[20] "Operations research", P. Rama Murthy [2007].

companies. Existing literature shows little attention to the problem of workforce management in the specific context of maritime CTs. Moreover, existing models assume to have sufficient operators for the workload of CTs and do not compute workforce shortage, which is one of the most risky situations for terminals, because it may result in costly vessel delays and in high penalties charged by shipping companies to terminals.

In order to overcome this gap, in this chapter, we have presented an Integer Linear Programming Model integrating personnel undermanning with the allocation of dockworkers to shifts, tasks and activities, while taking into account the long-term plan. Different operating and regulatory requirements have been taken into account for internal workers, external workers and manpower shortages. The model determines the optimal allocation of available workers and returns shortages in shifts, tasks, and activities, in order to contact overtime workers in time and serve vessels as scheduled. Moreover, the new cost formulation introduced for internal workers encourages the assignment of more productive workers to the activities with the highest priorities, making the assignment globally more efficient.

To evaluate the ability of the model in solving real world instances, numerical tests have been carried out on data provided by two important Mediterranean CTs. The testing phase has shown that this optimisation model can be effectively solved within a very short time by existing solvers, returning optimal solutions for all real size instances tested.

We have presented the manpower planning problem as it arises at MCT in Gioia Tauro and CICT in Cagliari, but it is worth noting that the general features of the problem are common to all similar port structures, especially to those mainly devoted to transhipment traffic that are traditionally more sensitive than regional ports to personnel undermanning and to possible delays in the service of mother vessels. The characteristics of generality of the model allow to adapt it to several operating configurations by only updating its parameters on the basis of the specific business needs.

CHAPTER 4

A Cost Scheme for Terminal Operation Delays

4.1 Introduction

The time spent in port is a fundamental issue in port areas and has always been an important determinant of attraction to port stakeholders, who typically evaluate the utility of each terminal and choose the terminal that shows the highest utility/efficiency [Ng and Yu, 2006]. Terminal efficiency is increasingly linked to the ability of the terminal to ensure rapid processing of vessels in compliance with the agreed handling times. To illustrate the concept, when a shipping operator[21] chooses a terminal, he evaluates not only the possibility of reaching the terminal on time, but also the possibility to leave it in a short time [Emeghara and Ndikom 2012, Konig 2002]. In fact, delays occurring at the terminal not only decrease the reliability of the liner service but can also generate additional operating costs for the shipping lines and logistics costs for the customers [Notteboom 2006]. This is the reason why contracts between shipping operators and terminal operators often contain specifications about the required minimum productivity on the quayside and penalties chargeable in case of non-compliance with times schedules.

As widely illustrated in the previous chapters, in manned CTs, where activities are mainly based on the labour of human resources, an optimal workforce management has a key role in achieving high levels of productivity and ensuring the conclusion of handling

[21] We use the term shipping operator in its broadest meaning: it may indicate shippers, ship owners as well as shipping liners.

activities on vessels within planned times. In particular, we have highlighted that in the daily management of manpower, the occurrence of shortages is one of the most tricky situations, and as such it should be avoided as much as possible. The lack of workers in a shift means that the missing part of the work planned for that shift cannot be completed within scheduled times, and longer times are needed to complete the operations. The completion of the unfinished work is hence postponed to the following shifts leading to inevitable lengthening of vessels turnaround times and additional related costs. Therefore, some major questions arise: *Which are the costs related to increased handling times at the terminal? Is it possible to provide a quantitative estimation of these costs?*

This chapter tries to give an answer to these questions. In particular, in section 2 we identify the cost factors related to longer than expected working times at CTs, distinguishing the point of view of a shipping operator from that of a terminal operator. Cost factors are divided into direct costs and indirect ones. Section 3 presents a scheme illustrating, from the vessel's point of view, the relationship between manpower shortages in the planned day and the costs related to extra-time spent by vessels in port to complete handling operations. It is worth saying that providing a quantitative estimation of the costs related to inefficiencies at the CT level is not a straightforward task. It involves many and diverse cost factors, some of which are difficult to estimate in monetary terms due to their nature, while some others must be estimated by sensitive information that traditionally CT operators are reticent in spreading, in order to protect their business. Literature does not help in this regard since very little has been written on this subject so far. Because of these practical difficulties, some assumptions have been made in order to build the cost scheme. Section 4 discusses two other important cost factors likely to come into play when a vessel is delayed at the terminal, i.e. logistics cost of goods carried and increased fuel consumption. Finally, concluding remarks are given in section 5.

4.2 Direct and indirect costs

A lengthening of working times on vessels produces operation delays and additional costs for both the shipping company and the terminal. Although this is a well-recognised problem in the real-world of container ports and in the scientific literature [see, among the most recent, Emeghara and Ndikom 2012, Notteboom 2006], only few studies have specifically analysed this topic. Some attempts to determine the costs related to operation delays occurring at the terminal level have been made focusing on a specific cost effect of port delays. Park and Dragovic [2009] for example try to analyse terminal's annual costs originating from ship's waiting due to port congestion at the CT of Busan (Corea). While developing a model to quantify the economies of scale in operating large containership, Cullinane and Khanna [2000], investigate the effect of port time in relation to the ship size by calculating the cost of the time in port as the product of the estimated number of days spent in port and the daily cost of the vessel. Moreover, interesting considerations are discussed by Notteboom [2006] who, while assessing the causes of schedule unreliability, discusses some costs related to delays and time losses within a liner service schedule and recognises inefficiencies occurring at the port as the main cause of schedule disruption.

Although the increasing costs caused by delays in port operations can be easily understood by everyone, their precise determination appears to be rather difficult. In the attempt to provide a more complete analysis of this issue, we have tried to identify the cost items which are likely to take place in case of delays in port operations, owing to manpower shortages or, more in general, to a sub-optimal management of human resources. As the effects in port operations depend on the perspective from which one analyses, we distinguish two main points of view: the terminal operator's point of view and the shipping operator's.

From the terminal perspective, costs related to longer operation times can be classified into two categories: *direct* costs and *indirect* ones. The former are mainly related to financial penalties contracted with shipping companies in case of non-compliance with the agreed working times. These costs are tangible for the terminal operator and can be easily calculated according to the indications contained in the contracts. Unlike *direct costs*, *indirect costs* may be more difficult to perceive and estimate, and they can include diverse cost factors:

- costs related to a sub-optimal use of berths with arriving vessels forced to wait for an available mooring in the harbor [Legato and Mazza 2001]. The waiting time for a berth when a ship arrives in port is a major factor for shipping lines [Barton and Turnbull 2002];
- greater risk factor for workers due to an increased pressure to complete the workload quickly;
- social costs related to increasing contamination caused by pollution on both the seaside (vessels waiting in the harbor) and the landside (waiting trucks);

- slowdown of terminal activities and loss of efficiency, which in the long term can lead to undesirable implications on terminal reputation.

From the vessel's perspective, costs related to longer operation times can also be divided into *direct* and *indirect* costs.

Direct costs can include increased mooring costs (if any) and economic penalties for delays at the next port of call. Indirect costs typically include:

- costs borne by vessels during the extra-time spent at the terminal to complete backlog;
- costs of schedule disruption.

If on the one side direct costs can be smoothly calculated on the basis of current costs and existing agreements, on the other side estimating indirect costs can be a more challenging process. In order to have a better understanding of the extent of the problem addressed, it may be useful to focus on a few points.

Nowadays, in the competitive environment of the container shipping business, shipping companies are increasingly focused on designing liner services characterized by short transit times and high degree of schedule reliability. Container vessels usually operate on closed routes (sequence of calling ports) and follow a schedule of sailings, i.e. a published timing of a route of a specific vessel. In order to offer a good level of service to their customers, shipping lines are keen to respect schedules as planned [Fagerholt 2004, Notteboom and Rodrigue 2008]. However, delays and time losses can disrupt schedules with negative consequences on schedule reliability if corrective measures are not taken in time. There are various causes of delays, Notteboom [2006] classifies them into 4 main groups: terminal performances below expectations, disruptions in port access, maritime passages (Suez and Panama Canal) and chance (weather, mechanical problems, etc.). In particular, delays due to port inefficiencies are recognised to be the main cause of schedules disruption, leading to negative impact on schedule reliability[22] [Notteboom, 2006]. The differences, even the small ones, between the actual execution time and the scheduled time have repercussions on the vessel cycle, on the synchronization of port cycles, on sailing times, and on the scheduling of next ports. Shipping companies bargain with CTs the number of movements per hour. Starting with this information, a shipping company can determine the amount of time its vessel stays in

[22] According to the results of a survey performed among shipping lines in 2004 on the East Asia – Europe route, port inefficiencies are the first source of schedule unreliability with a percentage higher than 86% [Notteboom, 2006].

a port before heading to another one, where the vessel is expected at a certain time. If the plan in a CT is not met, the whole plan may vary [Della Corte 2002]. Arriving at the next port, the vessel will not find the berth available for berthing, nor the facilities, nor the dockworkers ready to work on it.

Delays can decrease the reliability of the liner service, produce additional costs linked to unproductive vessel time and they can also lead to extra logistics costs depending on the goods carried. It is worth noting that delays produce a decrease in schedule reliability only if no corrective actions are taken in order to remedy the situation; corrective measures obviously have a cost. Leaving out more drastic but also less common measures such as the cancellation of one or more port of calls or the *cut and run* action,[23] the most common way to compensate for the time lost in port is by increasing the vessel speed in order to catch up part of the delay, but higher vessel speed means higher fuel costs [Wang and Meng 2012, Wang *et al.* 2013, Cariou and Notteboom 2011].

On the basis of the above considerations, it is reasonable to assume that there are three main indirect cost factors that have to be taken into account when a vessel is delayed at the port:

- costs borne by vessels during the extra-time needed to complete handling operations;
- logistics costs linked to delays in cargo delivery;
- increased fuel costs in the attempt to catch up part of the delay.

In the following paragraphs we try to give an analytical interpretation of these three cost items.

4.3 A descriptive cost scheme for operation delays

4.3.1 Costs borne by vessels

This paragraph presents a cost scheme illustrating the relationship between manpower shortages occurring in the day, and the costs related to the extra-time spent by the vessel in port to complete handling operations, from the vessel's point of view.

In our meetings, the maritime logistics experts often highlighted the importance of cutting operation times at the terminal and of respecting scheduled handling times. They

[23] Crane operations on a vessel are stopped before concluding loading /unloading of containers so that the vessel can leave the port on schedule.

motivated this necessity with the high costs borne by vessels during the time spent in port. In fact, in liner shipping, only sailing makes money, while berthing does not produce any profit, but it is, in any case, an essential part of the transport chain. Although berthing times are an unavoidable part of a scheduled liner service and their cost is calculated and offset by the profit deriving from the transport service, longer than expected berthing times produce only additional costs that reduce the profit. When asked about the amount of the costs attributable to an extra day spent by the vessel in port, our respondents always answered indicating an amount comparable to the daily fixed cost of the ship concerned. This aspect suggested that we calculate the costs borne by vessels during the extra time spent in port as a linear proportion of their fixed cost. In particular, we develop a cost scheme in which the Operation Delay Cost (ODC) borne by a vessel depends on the extra time needed to complete operations on it. Since our original aim was to evaluate the economic effects of shortages occurring in the daily management of manpower, the extra time is calculated as a function of the operators missing in the day. The cost scheme is described below.

To determine ODCs, we assume that the costs borne by vessels while berthing at ports mainly depend on vessel's fixed costs, that are traditionally divided into three major cost categories [US DTMA, 2011]:

- voyage costs (fuel and port charges);
- capital costs (principal and interest);
- operating costs.

If we take no notice of voyage costs, which are mainly related to the time that a vessel spends sailing, the extra-cost can be calculated as a proportion of capital and operating costs.

Capital costs take into account the purchase cost of the vessel and the depreciation during its useful life. Table 4.1 shows Capital Cost shares for three classes of container vessels, selected according to their capacity in TEUs. Capital Cost shares are derived from the average purchase costs of vessels and calculated assuming a thirty-year useful life[24].

Operating costs are costs associated with the day-to-day running of the ship. The maritime industry typically defines operating costs to include crew, stores and lubes, maintenance and repair, insurance costs, and overhead costs. Table 4.2 shows Operating Cost shares for the same three classes of container vessels reported in Table 4.1. The

[24] To calculate the annual capital cost we used the Straight Line Depreciation Method.

values shown are derived from the operating costs data provided by an important shipping agency[25]. Table 4.3 shows the Total Cost shares for the three classes of container vessels. Total Cost shares are calculated as the sum of Capital and Operating Cost shares listed in Tables 4.1 and 4.2.

Table 4.1 - Capital Costs shares.

Vessel Type	Capacity [TEUs]	Capital Cost Shares [USD]			
		Annual share	Daily share	6-hour shift share	Hourly share
Panamax	4.000	1.533.333	4.201	1.050	175
Post Panamax	6.000	2.500.000	6.849	1.712	285
Post Panamax Plus	10.000	3.566.667	9.772	2.443	407

Source: own elaboration on the basis of Drewry Shipping Consultant data.

Table 4.2 - Operating Costs shares.

Vessel Type	Capacity [TEUs]	Operating Cost Shares [USD]			
		Annual share	Daily share	6-hour shift share	Hourly share
Panamax	4.000	9.307.500	25.500	6.375	1.063
Post Panamax	6.000	12.045.000	33.000	8.250	1.375
Post Panamax Plus	10.000	14.600.000	40.000	10.000	1.667

Source: own elaboration on the basis of Drewry Shipping Consultant data.

Table 4.3 - Total Costs shares.

Vessel Type	Capacity [TEUs]	Total daily Cost [USD]	Total 6-hour Cost [USD]	Total hourly Cost [USD]
Panamax	4.000	29.701	7.425	1.238
Post Panamax	6.000	39.849	9.962	1.660
Post Panamax Plus	10.000	49.772	12.443	2.074

Source: own elaboration on the basis of previous data.

Any delay in handling operations produces a lengthening in vessel turnaround times. To evaluate how the lack of an operator may affect vessel operation delays, with the support of terminal experts, we have tried to quantify the effects of the lack of an operator for each possible driving task in a vessel gang.

We consider a sample vessel gang made up of 1 quay craner, 2 yard craners and 3 truck trailer drivers, then we determine an average productivity for each task. Many terminal

[25] Drewry Shipping Consultant.

operators keep statistics on labour productivity that are adopted for internal purposes or relations to customers. In our case, average productivities for each task are estimated from historical data of a Mediterranean CT with a throughput of 700.000 TEUs per annum, working with the indirect operation system based on RTG cranes plus trucks. Values of average productivity for each task are reported in Table 4.4. For example, a quay craner handles on average 22 TEUs per hour, i.e. 132 TEUs per 6-hour shift.

Table 4.5 shows the effects of operator shortages in a 6-hour shift for all possible driving tasks of a vessel gang. The second column indicates how many containers are not handled, due to the lack of 1 quay craner, 1 yard craner and 1 truck trailer driver respectively. For example, when there is 1 truck trailer driver missing in a shift, 44 TEUs are not handled, according to the estimated values of productivity given in Table 4.4. The third column indicates the related operation delay, i.e. how long a vessel gang should work on containers not yet handled. The remaining columns indicate the related Operation Delay Cost for each type of vessel. For example, an operation delay of 2 hours generated by 1 missing truck trailer driver results in an Operation Delay Cost amounting to 3.321 USD for a Post Panamax vessel, according to the cost values listed in Table 4.3. It is worth noting that the value of the Operation Delay is calculated assuming that only 1 vessel gang works to complete the backlog. The value of the Operation Delay and the related ODCs would be lower if more gangs worked simultaneously to complete the operations.

Table 4.4 - Average Productivity – RTG system.

Task	TEUs/h	TEUs/6-hour shift
Quay craner	22	132
Yard craner	11	66
Truck trailer driver	7,3	44

Source: own elaboration on the basis of container terminal data.

Table 4.5 - Operation Delay Costs – RTG system.

Task in shortage in a six-hour shift	TEUs not handled in a 6-hour shift	Operation Delay [h]	ODC - Operation Delay Cost [USD]		
			Panamax	*Post-Panamax*	*Post-Panamax Plus*
1 Quay craner	132	6	7.425	9.962	12.443
1 Yard craner	66	3	3.712	4.981	6.221
1 Truck trailer driver	44	2	2.475	3.321	4.148

Source: own elaboration on the basis of previously mentioned data.

Since the effects of shortages depend on the task missing in a vessel gang, we also want to calculate the effects of manpower shortages in the case of a typical vessel gang that operates in a terminal working with the direct transfer system based on straddle carriers. We are now considering a standard vessel gang made up of 1 quay craner and 4 straddle carrier drivers. Average productivities, derived from a Mediterranean CT with an annual throughput that exceeds 2 million TEUs and that works with the direct transfer system, are listed in Table 4.6. Table 4.7 is organised as Table 4.5 and shows the effects of operator shortages in a 6-hour shift for each possible task of the vessel gang considered. Looking at the data listed in Tables 4.5 and 4.7, it should be noted that the effects of the lack of an operator vary depending on both the average productivities and the configuration of the vessel gang. The latter depends on the terminal operating system adopted in the terminal. Excluding the lack of the quay craner, which always produces a total stop of the handling activity in its vessel gang, the lack of an operator, in case of a direct transfer system, has a comparatively lower impact on the total handling process than an operator missing in a vessel gang based on the indirect transfer system.

Table 4.6 – Average productivity – SC system.

Task	TEUs/h	TEUs/6-hour shift
Quay craner	28	168
Straddle carrier driver	7	42

Source: own elaboration on the basis of container terminal data.

Table 4.7 - Operation Delay Costs – SC system.

Task in shortage in a six-hour shift	TEUs not handled in a 6-hour shift	Operation Delay [h]	Operation Delay Cost [USD]		
			Panamax	*Post-Panamax*	*Post-Panamax Plus*
1 Quay craner	168	6	7.425	9.962	12.443
1 Straddle carrier driver	42	1,5	1.857	2.490	3.111

Source: own elaboration on the basis of previously mentioned data.

4.3.2 Logistics costs and increased fuel costs

Operating delays not only produce extra costs in the form of additional costs borne by shipping lines during the extra-time spent in port but, as seen in the first paragraphs, they may also have a negative impact on the reliability of the liner service, thus leading to additional logistics costs for the final customers due to the increased inventory and production costs [Notteboom, 2006].

This paragraph analyses the potential monetary effects produced by delays on port operations, with a particular focus on the additional logistics costs for the customers and the higher fuel costs incurred by shipping companies that attempt to catch-up part of the delay increasing their sailing speed so as to respect the liner service schedule.

Logistics Costs

We said that time is always a factor of competitiveness in liner shipping and that the offer of short roundtrip times is essential for every shipping line. In any case, the importance of the time factor varies depending on the particular market segment and it becomes essential when the goods involved are time sensitive (i.e. goods with a short life cycle or elevated depreciation) as longer transport times create opportunity costs and could lower their economic value. It is quite difficult to estimate the logistics costs resulting from a port delay as these costs may vary depending on several factors such as the nature of the goods involved, the economic value of the goods[26], or further effects that delays may produce on the wider production chain. Notteboom [2006] provided an estimate of the logistics costs resulting from a delay of 24h for a load container with an estimate value of 40.000 €, by dividing the logistics costs in opportunity costs and economic depreciation. The first are estimated in 3,3 € per day (3% per year) while the latter in 11 € per day (10% per year).

We have used these cost values to calculate the logistics costs related to several port operation delays. The resulting costs are listed in Table 4.8. Calculations are done by considering the case of a Panamax vessel carrying 3.000 TEUs load of goods with an average value of 40.000 € per TEU.

It is fair to say that these estimations can only be indicative and that they might be higher when the late delivery of goods produces further disruptions in the production line of a product, with a negative impact on the total supply chain.

[26] Verbeke and Notteboom [2003] stated that the average value of containerised goods differs substantially among trade routes.

Table 4.8 – Logistics cost for several port delays.

Port delay [h]	Logistics Cost [€]	Economic Depreciation [€]	Total Customer Cost [€]
2	825	2.750	3.575
4	1.650	5.500	7.150
6	2.475	8.250	10.725
8	3.300	11.000	14.300
10	4.125	13.750	17.875
12	4.950	16.500	21.450

Source: own elaboration on the basis of Notteboom [2006] values.

Fuel costs

Nowadays, given the increased fuel prices, bunker costs are a consistent part of the total running cost of modern container vessels, representing about three quarters of the total operating cost [Ronen, 2011]. In recent years, the high incidence of bunker costs on total operating costs has led many service planners to adopt intervention measures in the attempt to reduce bunker fuel consumption levels. Notteboom and Vernimmen [2009], in their work, listed several types of initiatives for managing fuel consumption and analysed how increased bunker prices have had an impact on the design of liner services in terms of vessel speed, vessel size and number of vessels per loop on the Europe–Far East trade. According to their analysis, carriers are now focusing on a smaller number of ports of call and on slow steaming practice. With the latter, we refer to the practice of transoceanic container vessels to sail at reduced speed in order to contain fuel consumption. Since the beginning of the last global economic crisis in the second half of 2007, slow steaming has been implemented by the main liner shipping companies in order to face rising fuel costs [Cariou and Notteboom 2011; Meyer *et al.* 2012]. In line with the estimates of the National Ports and Waterways Institute [2011], nearly all global shipping lines are now using slow steaming to save money. Even if minor differences exist among slow steaming policies implemented by different shipping companies, speed of 17/18 knots is typically referred as slow steaming [Maersk Group 2011, Hapag-Lloyd 2011] while lower speed is normally called super slow steaming.

It is fair to say that if on the one hand adjusting the sailing speed of vessels allows for substantial cost savings [Meyer *et al.* 2012, Khor *et al.* 2012], on the other hand it produces new costs for container business resulting in increased travel times and higher inventory costs which may potentially result in lower revenues for vessel operators [Bergh 2010, Ronen 2011]. When the reduction of the speed is significant, it may be necessary, in order to avoid these negative consequences, to increase the number of vessels deployed on the route so as to maintain the desired frequency [Vernimmen *et al.* 2007]. The problem of finding a good trade-off between the reduction of the service speed and the increase in the number of vessels deployed has represented the focus of recent studies on the general liner service design problem [Ronen 2011, Alvarez 2009, Brown *et al.* 2007][27], in any case, this goes beyond the purpose of this study.

As for what concerns slow steaming, it offers the possibility to catch-up delays. In fact, in the attempt to reduce roundtrip delays and reach the next port of call on time, shipping lines may decide to speed up their vessels resulting in higher bunker costs [Bendall and Stent 1999; Notteboom 2006]. A speed increase means an increase in fuel consumption.

It is well established that the relationship between fuel consumption and sailing speed is not linear. Bunker fuel consumption is recognised to be proportional to the third power of the vessel sailing speed, this relation is also confirmed by empirical evidence [Alvarez, 2009; Vernimmen *et al.* 2007]. Kontovas and Psaraftis [2011] suggested using an exponent of four or greater when the speed is greater than 20 knots.

As shown in the fuel consumption/speed curve (Fig. 4.1), it is important for vessel operators to maintain their speed within an appropriate range of speeds so as to have reasonable fuel costs. Particular attention is needed when increasing the speed where the curve is steeper, in fact a small speed increase produces big penalties in terms of fuel consumption. On the contrary, speed can be augmented with very little increase of consumption where the curve is flatter.

To give an evaluation of the increased fuel consumption related to higher sailing speeds, some published data are here used to calculate the effects in terms of higher fuel consumption for a 10.000 TEU container vessel, which increases its sailing speed in the attempt to reduce the delay accumulated during port activities.

To calculate sailing times at different vessel speeds, we assume the next port of call to be at a distance of 400 nm (approximately the distance between the ports of Hamburg and Antwerp). Table 4.9 lists the sailing times at several speeds and the corresponding fuel consumption per day. The last column depicts the corresponding daily fuel cost at mid-2013 bunker prices[28].

[27] For an updated review on mathematical solution methods for bunker consumption optimisation problems see Wang et al. [2013].

[28] 590 USD/Ton (June 2013). Data from http://www.bunkerworld.com/prices/port/ae/fjr/

Fuel consumption has been calculated considering the curve fuel consumption/service speed estimated by Notteboom and Vernimmen [2008] for a 10.000 TEU container vessel (Fig. 4.2).

Assuming that the designed service speed of the vessel was 20 knots (slow steaming), the vessel should increase its sailing speed by 25% in order to catch up four hours of delay. Looking at the data in bold, the corresponding increase in fuel consumption would be about 55%, with a cost increase of about 40.000 USD.

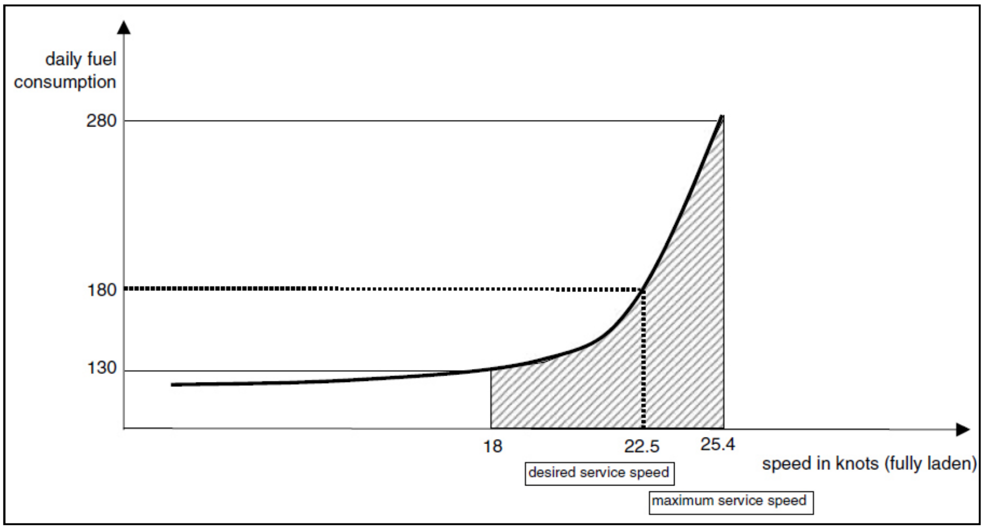

Figure 4.1 - Curve of daily fuel consumption/vessel speed.
Source: Notteboom [2006].

Table 4.9 – Fuel cost at several sailing speeds.

Sailing speed [knots]	Sailing Time [h]	Sailing Time [days]	Fuel consumption [Tons/day]	Fuel Cost [USD/day]
18	22,2	0,93	99,07	58.454
19	21,1	0,88	109,65	64.693
20	**20,0**	**0,83**	**120,00**	**70.800**
21	19,0	0,79	130,95	77.262
22	18,2	0,76	140,91	83.136
23	17,4	0,72	156,52	92.348
24	16,7	0,69	173,61	102.431
25	**16,0**	**0,67**	**186,00**	**109.740**
26	15,4	0,64	198,72	117.244

Source: own elaboration.

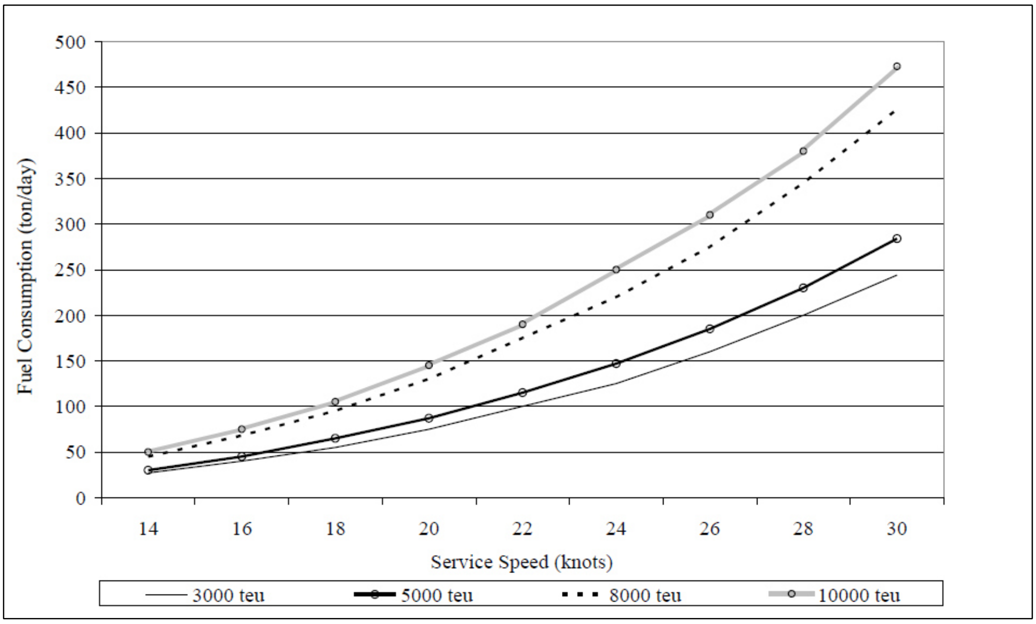

Figure 4.2 - Curve fuel consumption/service speed for four types of container vessels. Source: Notteboom [2006].

4.4 Conclusion

The time in port and port productivity are crucial elements for the commercial success of container vessels. In the first chapters, we have repeatedly stressed the importance of having low shortages in the management of the workforce, in order to avoid a loss of efficiency of the terminal and additional costs for the subjects involved.

In this chapter we tried to analyse the costs related to the delays in port operations resulting from shortages occurring in the planned day, even if analogous conclusions can be derived from any delay in general. We have identified the costs related to port delays, from the perspective of the two main players involved: the terminal operator and the vessel operator.

A complete evaluation of the costs related to the lengthening of handling times in port is rather complicated. Terminal operators are traditionally reticent in spreading sensitive information related to their business and many of the cost parameters involved are difficult to estimate in monetary terms.

To understand better the extent of the issue addressed, we have provided an estimation of three important cost items related to longer port operations times from the vessel operator perspective:

- costs borne by vessels during the extra-time needed to complete handling operations;

- logistics costs linked to delays in cargo delivery;
- increased fuel costs in the attempt to catch up part of the delay by increasing the sailing speed.

With regard to the first cost item, we have developed an evaluation scheme illustrating the relationship between manpower shortages occurring in the day, the extra-time needed to complete operations on vessels and the related costs. Since the effects of manpower shortages depend on what operating system is used, we have analysed the impact of shortages in the two most common terminal operating systems, i.e. the direct transfer system based on SCs and the indirect transfer system based on RTGs and trucks.

We have then estimated the logistics costs and the increased fuel costs related to several port delays, by making some assumptions about vessel capacity, amount of containers carried, length of the route and average value of goods.

These cost estimations help understanding the importance of the effects of delays occurring at the terminal level from the vessel perspective. Moreover, it is fair to say that these estimations can only be indicative and may vary depending on several factors such as the operating system used at the terminal, the ship involved, the nature of the good carried, the customer, etc. Besides, costs resulting from port delays might be more elevated when the late delivery of goods produces further disruptions in the production line with negative impact on the wider supply chain.

Finally, this cost scheme has been built primarily to calculate the effects of manpower shortages from the vessel point of view. It is worth noting that it can be extended to any type of disruption that may occur in the terminal and that produces a delay in handling operations. Prohibitive weather conditions, strikes or mechanical failures are some of the most common causes of disruptions of terminal activities. Moreover, recent regulations in the area of maritime transport security and the application of new procedures, such as the container scanning practice, can produce a further slowdown of the terminal's activities with effects in terms of delays in handling operations [HPC 2010, Acciaro and Serra, 2013]. The outcomes described in this chapter can easily be extended also to evaluate the effects of these disruptions.

CHAPTER 5*

The Optimal Allocation of Human Resources in Container Terminals: a two-day Planning Horizon

5.1 Introduction

In Chapter 3 we presented an optimisation model to determine the optimal daily allocation of dockworkers to shifts, tasks and terminal activities, highlighting manpower shortages when these occur. The tests performed show that the optimisation model was able to determine the optimal allocation of operators using a 24-hour planning horizon, which is the standard used in the literature [Legato and Monaco, 2004]. However, one may ask: *How may the model work if a longer planning horizon is used? In particular, considering the crucial role of manpower shortages in terminal activity, what are the effects of using a longer planning horizon in terms of shortages occurring in the planned day?* This chapter tries to give an answer to these questions by investigating the effects of the use of a longer planning horizon in the operational management of HRs in CTs.

In particular, since a longer-than-one-day planning horizon may make use of more data, we aim at investigating the effects that a planning horizon longer than the standard daily one has on the decisions concerning the first day planned. A two-day planning horizon will be included in our optimisation model and used in a rolling horizon fashion.

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* **This chapter is mainly based on Di Francesco, Fancello, Serra and Zuddas [2014].**

The chapter is then structured as follows: section 2 discusses the factors involved in the definition of the planning horizon length used in the operational allocation of HRs in CTs; in section 3 a two-day planning horizon model is used in rolling horizon fashion to solve a numerical real-world instance and its decisions are compared with those taken by the 24-hour horizon model; in section 4 the decisions taken by the two models are compared by means of the cost scheme presented in chapter 4, in terms of number of shortages occurring, operation delays and the resulting costs for shipping companies. Lastly, section 5 presents a summary of the conclusions we have reached.

5.2 The length of the planning horizon

The main hypothesis that we make in this chapter is that the use of a longer-than-one-day planning horizon, making use of more data, may produce a better use of the resources available. In fact, the length of the planning horizon is an important issue in problem planning and some studies demonstrate that often the results of management problems can be affected by changes in the length of the planning horizon [Choong *et al.* 2002, Holmberg *et al.* 1998, Bregman 1991]. This is the reason why to get valid solutions, the length of the planning horizon should always be determined carefully [Crainic *et al.* 1993]. Related literature shows a fair number of studies discussing the importance of the planning horizon length, especially in the field of production planning [Russel and Urban 1993, Matta and Guignard 1995], while comparatively few works are available on this topic in the specific context of CT planning. The majority of these studies address the planning horizon issue with respect to the management of empty containers [Choong *et al.* 2002, Crainic *et al.* 1993, Cheung and Chen 1998]. Even if no studies discussing the planning horizon length have been found in the specific field of the HRMP in CTs, there are some general considerations that can also be extended to our problem and that can of help in setting the more suitable length of the planning horizon in the operational management of workers in CTs.

The studies analysed seem to suggest that there are at least three main considerations to keep in mind in the choice of a good planning horizon:

1. The demand data is more precise at the beginning of the planning horizon [Pisano 2008, Legato and Monaco 2004];
2. The longer is the planning horizon, the most relevant is the role of uncertainty [Fancello *et al.* 2011, Russell and Urban 1993];

3. The horizon extension allows to include additional information about the future demand [Crainic *et al.* 1993, Dejax *et al.* 1992, Matta and Guignard 1995, Holmberg 1998].

Let us analyse the specific problem of HRA in CTs according to these considerations.

As extensively seen in the previous chapters, handling activities in CTs are closely related to vessels' arrival time in port. However, the arrival time of a vessel is a parameter affected by significant uncertainty [Fancello *et al.* 2011, Fadda *et al.* 2013] and the confidence in its evaluation becomes acceptable only when the actual arrival of the ship in port is approaching. Consequently, if on the one hand the extension of the planning horizon would allow the visibility of more data, on the other hand, it might lead to important planning errors due to the higher level of uncertainty that characterizes the data. A reasonable trade-off is needed.

According to the ETAs periodically sent by shipping companies, point forecasts on the activities of a CT are reasonably reliable within 72 hours from the moment of planning HRA[29]. Therefore, these forecasts can be used to carefully plan HR in the interval between 24 and 72 hours after the planning moment.

To limit the planning horizon length to an interval in which problem data are accurate enough, a two-day planning horizon seems to be a reasonable choice: it is wide enough to include important planning aspects and sufficiently small for an acceptable accuracy of data application.

The two-day planning horizon model is then used in a rolling horizon environment, i.e. decisions are taken by the model for all periods of the planning horizon, but only the decisions concerning the first day (in the interval between 24 and 48 hours) are *Here and Now decisions*, i.e. they must be implemented immediately; decisions related to the second day (between 48 and 72 hours) are *Recourse decisions*, which can be changed in the next day when new data is available. To clarify, in the next day the previous second day becomes the new first day, a new day is added at the end of the planning horizon and the model is run again (see Figure 5.1).

As the daily model, the two-day horizon model is required to run quickly 24 hours before the planned day. Decisions will be implemented between 24 and 48 hours after the

[29] Arrival times are precisely known within this interval by the ETAs sent by shipping companies to ports: 72, 48 and 24 hours before the arrival of vessels.

planning moment, whereas at this point of time no decisions can be made for the first 24 hours.

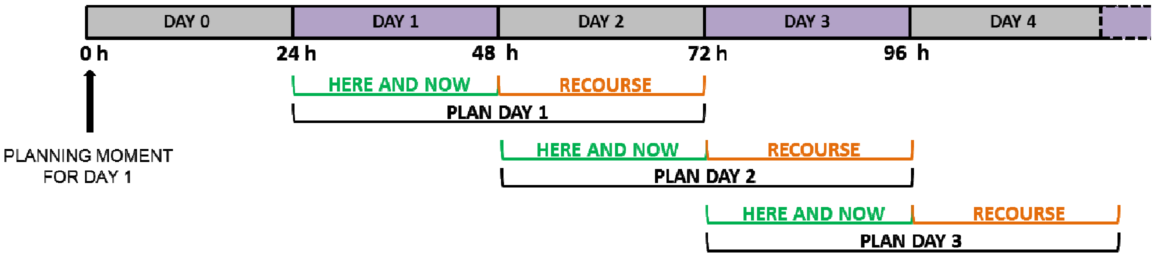

Figure 5.1 - Rolling Horizon.
Source: author.

5.3 A numerical experimentation on CICT

In this paragraph numerical tests are carried out to illustrate the ability of the two-day horizon model to reduce operator shortages occurring in the planned day with respect to the standard one-day horizon model.

The experimentation is performed using the model in a rolling horizon fashion, in which only *here-and-now* decisions concerning the first day are implemented. On the next day, when new decisions must be made and new information becomes available, the previous second day becomes the new first day, a new day is added at the end of the planning horizon and the model is run again.

Since decisions related to the second day of the planning horizon are not of immediate relevance, the use of the model in a rolling horizon environment allows to assign higher penalties to shortages occurring in the first day, whose decisions have to be implemented immediately, in order to encourage day by day a more effective allocation of resources.

As in Chapter 3, data used in this application have been realistically generated from work days at CICT:

- the working day is divided into 4 shifts of 6 hours each;
- the set of internal operators is taken for granted by the terminal, as well as their costs, main tasks and shifts according to the long-term plan.
- a number of external operators is given, as well as their unitary costs. These workers are supposed to perform truck trailer driving tasks only.

- the vessel gang is made up of 1 quay craner, 2 yard craners and 3 truck trailer drivers while the housekeeping gang has 2 yard craners and 3 truck trailer drivers[30];
- the productivity index p_{ijkz} is taken from the terminal's historical data;
- the priority g_z of vessel operations is supposed to be twice the housekeeping priority;
- the index of activity complexity a_z is supposed to be constant in this application;
- the higher the task level, the higher the overtime pay for workers performing that task, the higher the shortage costs in the model.

The two-day horizon model has been implemented by GNU MathProg modelling language and, as in the case of the daily model, instances have been solved using GLPK 4.39 and Cplex 11.1, running on a PC with a 3.00 Ghz processor and 16 Gb of memory.
Several two-day planning horizon instances have been solved and compared to pairs of one-day instances with identical data on the first and the second day.

The first problem instance involves 2 days, denoted by *Day 1* and *Day 2*. To illustrate work demand data in the first problem instance, we refer to Table 5.1 and Table 5.2. Tables are organised as Tables 3.2 and 3.3 in Chapter 3; they show the work demand of the day in terms of number of gangs required to perform vessel and housekeeping activities at each shift (Table 5.1), and number of workers for each shift and task (Table 5.2), distinguishing between vessel and housekeeping gangs, denoted by VG and HG respectively. For instance at shift 5, 4 yard craners (*yc*) are demanded to serve vessels and 2 for housekeeping. Since quay craners (*qc*) are not involved in housekeeping activities, their demand is denoted by "-". Data in Tables 5.1 and Table 5.2 are used to generate the first instance, which is denoted as *Days_1_2*.

To illustrate decisions, we refer to Table 5.3. Lines indicate whether the work demand is met by internal operators, external ones or whether there is a shortage. Columns represent shifts and are divided into vessel and housekeeping gangs, which are denoted by VG and HG respectively. For instance, according to the last line in Table 5.2, the total work demand of truck trailer drivers (*tt*) at shift 3 was 15 (12 for vessels and 3 for housekeeping). The demand of truck trailer drivers at shift 3 is satisfied by 2 internal operators deployed on vessel gangs, 10 external operators deployed on vessel gangs and 3 external operators deployed on housekeeping gangs. No shortages are observed in *Day 1*. Shortages in shifts from 5 to 8 are not of immediate relevance, because these decisions

[30] We propose for our experimentation a specific configuration of gangs, which is taken from the port of the case. However, the model is general and can be initialized with all possible gang configurations (for instance, 4 or 5 truck trailers instead of 3).

(*recourse*) must not be implemented immediately and may be changed in the next day, when new information is available. The detail of the problem instance *Days_1_2* is reported in Appendix 2.

Table 5.1 - Requested number of gangs in *Day 1* and *Day 2*.

Days_1_2	**Day 1**				**Day 2**			
	Shift 1	*Shift 2*	*Shift 3*	*Shift 4*	*Shift 5*	*Shift 6*	*Shift 7*	*Shift 8*
VG – Vessel Gangs	4	4	4	2	2	4	4	4
HG – Housekeeping Gangs	0	1	1	1	1	1	1	0

Source: author.

Table 5.2 - Requested number of operators in *Day 1* and *Day 2*.

Days_1_2	**Day 1**								**Day 2**							
	Shift 1		*Shift 2*		*Shift 3*		*Shift 4*		*Shift 5*		*Shift 6*		*Shift 7*		*Shift 8*	
	VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
qc	4	-	4	-	4	-	2	-	2	-	4	-	4	-	4	-
yc	8	0	8	2	8	2	4	2	4	2	8	2	8	2	8	0
tt	12	0	12	3	12	3	6	3	6	3	12	3	12	3	12	0

Source: author.

Table 5.3 – Assignment of operators in instance *Days_1_2*.

Days_1_2		**Day 1**								**Day 2**							
		Shift 1		*Shift 2*		*Shift 3*		*Shift 4*		*Shift 5*		*Shift 6*		*Shift 7*		*Shift 8*	
		VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
Internal Operators	*qc*	4	-	4	-	4	-	2	-	2	-	4	-	4	-	4	-
	yc	8	0	8	2	8	2	4	2	4	2	8	1	8	2	8	0
	tt	5	0	3	0	2	0	6	3	6	3	3	0	3	0	5	0
External Operators	*tt*	7	0	9	3	10	3	0	0	0	0	3	0	4	0	1	0
Operator Shortages	*qc*	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
	yc	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	tt	0	0	0	0	0	0	0	0	0	0	6	3	5	3	6	0

Source: author.

We aim to show how previous decisions would change if a daily planning horizon is used. Table 5.4 shows the same work demand as in the first day of the previous instance *Days_1_2*.

Data in Table 5.4 are used to generate the second instance, which is denoted as *Day_1*.

Table 5.5 shows the solution obtained for this instance. Several *tt* drivers miss at shifts from 1 to 3. For example, 7 *tt* drivers miss at shift 3 (4 for vessels and 3 for housekeeping), whereas no shortages were detected in instance *Days_1_2*, as shown in Table 5.3. The detail of the problem instance *Day_1* is reported in Appendix 3.

Table 5.4 - Requested number of operators in *Day 1*.

Day_1	***Shift 1***		***Shift 2***		***Shift 3***		***Shift 4***	
	VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
qc	4	-	4	-	4	-	2	-
yc	8	0	8	2	8	2	4	2
tt	12	0	12	3	12	3	6	3

Source: author.

Table 5.5 - Assignment of operators in instance *Day_1*.

Day_1		***Shift 1***		***Shift 2***		***Shift 3***		***Shift 4***	
		VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
Internal Operators	***qc***	4	-	4	-	4	-	2	-
	yc	8	0	8	2	8	2	4	2
	tt	6	0	2	0	2	0	6	3
External Operators	***tt***	5	0	6	3	6	0	0	0
Operator Shortages	***qc***	0	-	0	-	0	-	0	-
	yc	0	0	0	0	0	0	0	0
	tt	1	0	4	0	4	3	0	0

Source: author.

On the next day the model must be run again by rolling the planning horizon: the previous second day becomes the new first day and, in order to use a two-day planning horizon, a new day must be added after the first. These days are denoted by *Day 2* and *Day 3*. The work demand is represented in Table 5.6 and Table 5.7, which are organised as Table 5.1 and Table 5.2 respectively. Data in Table 5.6 and Table 5.7 are used to generate the third instance, which is denoted as *Days_2_3*.

It is worth noting that the work demand in shifts from 1 to 4 is identical to the previous workload in shifts from 5 to 8 in instance *Days_1_2*, because in this specific experimentation no new information is supposed to come between *Day 1* and *Day 2*. However, this is not a restriction, because any new information can be included.

Results are shown in Table 5.8, which is organised as Table 5.3. No shortages are observed in shifts from 1 to 4. Shortages in shifts from 5 to 8 are not of immediate relevance, because these decisions (*recourse*) must not be implemented immediately and can be changed in the next day. The detail of the problem instance *Days_2_3* is reported in Appendix 4.

Table 5.6 - Requested number of gangs in *Day 2* and *Day 3*.

Days_2_3	**Day 2**				**Day 3**			
	Shift 1	*Shift 2*	*Shift 3*	*Shift 4*	*Shift 5*	*Shift 6*	*Shift 7*	*Shift 8*
VG – Vessel Gangs	2	4	4	4	2	4	4	4
HG – Housekeeping Gangs	1	1	1	0	1	1	1	0

Source: author.

Table 5.7 - Requested number of operators in *Day 2* and *Day 3*.

Days_2_3	**Day 2**								**Day 3**							
	Shift 1		*Shift 2*		*Shift 3*		*Shift 4*		*Shift 5*		*Shift 6*		*Shift 7*		*Shift 8*	
	VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
qc	2	-	4	-	4	-	4	-	2	-	4	-	4	-	4	-
yc	4	2	8	2	8	2	8	0	4	2	8	2	8	2	8	0
tt	6	3	12	3	12	3	12	0	6	3	12	3	12	3	12	0

Source: author.

Table 5.8 - Assignment of operators in instance *Days_2_3*.

Days_2_3		**Day 2**								**Day 3**							
		Shift 1		*Shift 2*		*Shift 3*		*Shift 4*		*Shift 5*		*Shift 6*		*Shift 7*		*Shift 8*	
		VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
Internal Operators	*qc*	2	-	4	-	4	-	4	-	2	-	4	-	4	-	4	-
	yc	4	2	8	2	8	2	8	0	4	2	8	0	8	1	8	0
	tt	6	2	3	0	1	0	6	0	6	3	2	0	4	0	7	0
External Operators	*tt*	0	1	9	3	11	3	6	0	0	0	4	3	0	0	0	0
Operator Shortages	*qc*	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
	yc	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
	tt	0	0	0	0	0	0	0	0	0	0	6	0	8	3	5	0

Source: author.

Let us switch to the daily planning horizon. Table 5.9 shows the work demand, which is equal to the workload on the first day of the instance *Days_2_3*. Data in Table 5.9 are used to generate the fourth instance, which is denoted as *Day_2*.

Table 5.9 - Requested number of operators in *Day 2*.

Day_2	*Shift 1*		*Shift 2*		*Shift 3*		*Shift 4*	
	VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
qc	2	-	4	-	4	-	4	-
yc	4	2	8	2	8	2	8	0
tt	6	3	12	3	12	3	12	0

Source: author.

Results are shown in Table 5.10. Relevant personnel shortfall arises in this case: for instance, 1 *yc* and 8 *tt* drivers (5 for vessels and 3 for housekeeping) miss at shift 2. The detail of the problem instance *Day_2* is reported in Appendix 5.

Table 5.10 - Assignment of operators in instance *Day_2*.

Day_2		**Day 2**							
		Shift 1		*Shift 2*		*Shift 3*		*Shift 4*	
		VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**
Internal Operators	*qc*	2	-	4	-	4	-	4	-
	yc	4	2	8	1	8	2	8	0
	tt	6	3	3	0	1	0	7	0
External Operators	*tt*	0	0	4	0	11	0	5	0
Operator Shortages	*qc*	0	-	0	-	0	-	0	-
	yc	0	0	0	1	0	0	0	0
	tt	0	0	5	3	0	3	0	0

Source: author.

Therefore, the two-day planning horizon leads to lower shortages in workforce management, because it exploits the visibility of more data to make better decisions over two days. Moreover, shortages typically involve lower level tasks, which can easily be completed by additional workers, who can be deployed in overtime shifts.

Finally, we aim to illustrate the effectiveness of solvers GLPK 4.39 and Cplex 11.1 to solve the proposed model. The computational tests are shown in Table 5.11, in which each line describes a problem instance. It is important to note that both solvers return the same solution for all problem instances. CPU times are very short and, hence, they are far suitable for the operating requirements of transhipment CTs.

Table 5.11 - Computational performances.

Instance ID	Number of variables	Number of constraints	Objective Function		CPU Time (s)	
			GLPK	*Cplex*	*GLPK*	*Cplex*
Days_ 1_2	9032	5400	3725.5	3725.5	0.1	0.05
Day _1	2696	586	2456	2456	0.03	0.02
Days_ 2_3	9032	5520	3765.5	3765.5	0.1	0.04
Day _2	2696	706	2467.5	2467.5	0.03	0.02

Source: author.

5.4 Operation Delay Cost

This paragraph provides an estimation of ODC (Operation Delay Cost) associated to manpower shortages occurring in the planned day using the daily horizon model and the two-day horizon model. Estimations of ODC are made on the basis of considerations and cost values previously discussed in Chapter 4.

Table 5.12 shows the impact of personnel undermanning in vessel gangs under the hypothesis of serving only *Post-Panamax* vessels, as classified in Table 4.3. The impact is evaluated in terms of TEUs not handled, delays on vessel operations, and resulting ODC, as derived from Tables 4.4 and 4.5. For instance, 4 truck trailer drivers missing at shift 2 result in 176 TEUs not handled: 8 additional hours are required for a gang to complete vessel operations and the related ODC is estimated to amount to 13.284 USD. It is important to note that the overall ODC in the first day of instance *Days_1_2* is zero, because no shortages were detected in this case, in which a two-day planning horizon was used.

Table 5.12 – The effects of shortages arising in the solution of instance *Day_1*.

Vessel Type: Post-Panamax		Day 1			
		Shift 1	*Shift 2*	*Shift 3*	*Shift 4*
Operator Shortages	Quay craners (qc)	0	0	0	0
	Yard craners (yc)	0	0	0	0
	Truck trailer drivers (tt)	1	4	4	0
TEUs not handled in a 6-hour shift		44	176	176	0
Operation Delay [h]		2	8	8	0
ODC - Operation Delay Cost [USD]		3.321	13.284	13.284	0

Source: author.

As in the case of Table 5.12, Table 5.13 shows the effect of personnel undermanning arising in the solution of instance *Day_2*. In this case, 5 truck trailer drivers miss at shift 2 resulting in 220 TEUs not handled: 10 additional hours are required for a vessel gang to complete operations; the related ODC is estimated to amount to 16.600 USD. Even in this phase, it is important to note that the overall ODC in the first day of instance *Days_2_3* is zero, because no shortages were detected in that case, in which a two-day planning horizon was used.

Table 5.13 – The effects of shortages arising in the solution of instance *Day_2*.

Vessel Type: Post-Panamax		Day 2			
		Shift 1	*Shift 2*	*Shift 3*	*Shift 4*
Operator Shortages	Quay craners (qc)	0	0	0	0
	Yard craners (yc)	0	0	0	0
	Truck trailer drivers (tt)	0	5	0	0
TEUs not handled		0	220	0	0
Operation Delay [h]		0	10	0	0
Operation Delay Cost [USD]		0	16.600	0	0

Source: author.

5.5 Conclusion

This chapter aimed at investigating the effect of the planning horizon length on the HRAP in CTs. In particular, since a longer planning horizon allows the visibility of more data, we wanted to investigate the effect of using a planning horizon longer than the standard daily one in the operational management of the workforce. Furthermore, considering the crucial role of manpower shortages in the activity of a CT, we aimed to evaluate the effects of using a longer planning horizon in terms of reduction of shortages occurring in the planned day.

The definition of a proper planning horizon length in the field of the CT management has required some important considerations about the uncertainty that typically characterizes the demand for terminal activities. In fact, if on the one side, the extension of the planning horizon allows the visibility of more data, on the other side it may lead to important planning errors due to the higher level of uncertainty characterizing demand data related to vessels' arrival times. To limit the planning horizon length to an interval in which problem data are enough accurate, a two-day planning horizon has been adopted in this study considering the level of reliability of ETA information within 72 hours from the planning moment. Since labour regulations state that the assignment of operators has to be determined 24 hours before the planned day, these points forecast can be used to manage human resources in the interval between 24 and 72 hours after the planning moment.

The two-day planning horizon model has been used in a rolling horizon fashion to compare here-and-now decisions deriving from a one-day and a two-day horizon. Decisions are taken by the model for all periods of the planning horizon, but only the decisions concerning the first day are implemented immediately, whereas decisions related to the second day can be changed the following day, when new information is available.

The chapter has illustrated, by means of a numerical experimentation derived from real-world CTs, how operators' shortages in a day can be reduced in the model solutions if a two-day planning horizon is used instead of a standard daily one: a lower number of shortages occurs in the day planned when the model encompasses a two-day planning horizon in a rolling horizon fashion. We have then compared the impact of personnel undermanning that occurs when using the one-day and the two-day planning horizons in terms of operation delays and the related costs from the perspective of a shipping operator, who has to face larger-than-expected berthing times due to delays in port activities. The lower the workforce shortage, the lower the costs generated by operation delays, the more efficient and competitive the terminal in the shipping industry.

The application performed has shown that existing solvers can be successfully adopted in the CT management, because they can determine optimal decisions in realistic size instances within the time limits imposed by planning operations. In this study, one commercial and one freeware solver were effectively used.

Given their characteristics of generality and of adaptability, the optimisation model and the associate procedure of the extended planning horizon can be applied to many CTs and they will hopefully assist planners in managing human resources more efficiently.

Further considerations before concluding the chapter. Our optimisation model is supposed to operate in a deterministic environment in which complete information about the problem is available. Since demand data is supposed to be reasonably reliable in our planning horizon, the uncertainty characterizing planning activities is here gradually faced by using the two-day horizon model in a rolling horizon fashion and correcting recourse decisions day by day, when data application becomes more precise. A further extension of the planning horizon would allow to introduce in the model additional contingent constraints that today are only verified by means of ex-post evaluations (i.e. maximum number of working shifts per week for operator, maximum night shifts per month for operator, etc.), but it would also lead to a greater uncertainty of the data involved making traditional deterministic methods highly inadequate in providing good solutions, in particular, when the future differs significantly from its forecast. In this case, a diverse approach based on stochastic models should be more suitable and could constitute an interesting topic for future research.

CHAPTER 6*

Policy: Alternative scenarios of labour flexibility

6.1 Introduction

Today, it is widely accepted that the dynamics of port competition are strongly influenced by existing port labour regimes [Notteboom 2010, Van Hooydonk 2013, ISFORT 2010]. In the previous chapters, we proposed an optimisation model for the allocation of dockworkers and we demonstrated, by computational tests, how the use of the optimisation model and the associate procedure of the extended planning horizon can support terminal planners in managing HRs efficiently. However, in some CTs strict work regulations and insufficient labour flexibility may prevent an optimal use of the available resources and produce an increase in operating costs. In these cases, even an optimal resources management implemented through an effective analytical tool may not be sufficient for the terminal to ensure a competitive position in a market where competitors operate under more permissive regulations and at lower labour costs.

For example, let us consider the case of pure transhipment CTs[31] located in the Mediterranean Sea: Algeciras, Cagliari, Gioia Tauro, Malta, Port Said, Tanger and Taranto. Their competitiveness is mainly due to their proximity to the ideal route (Suez Canal - Strait of Gibraltar), which allows large container vessels to save several days of sailing. Currently,

*** This Chapter is mainly based on Fancello, Serra and Fadda [2013].**

[31] Pure transhipment container terminals are terminals in which transhipment traffic represents more than 90% of the total volume handled.

the competition among these CTs is distorted by economic and regulatory differences, which place European CTs in a significant disadvantage compared to their competitors located in the southern Mediterranean [PRIN 2011]. Focusing in particular on Italian CTs, they are characterized not only by a greater taxation of transhipment activities, higher infrastructure and energy costs with respect to their nearby competitors, but also by more restrictive labour regulations and higher labour costs[32] that generate a significant disadvantage in terms of competitiveness [Eurispes Report 2011]. High productivity and high flexibility of labour have a cost. When high labour cost is not corrected by advantages in flexibility and productivity, the terminal faces a competitive disadvantage.

It is well recognised that labour regulation has a fundamental role in determining both day-to-day levels of efficiency and the long-term dynamics of competitiveness among ports [Barton and Turnbull 2002]. Labour flexibility, in particular, is one of the most important determinants for the resulting port performances, as the demand of terminal activities may fluctuate widely from one day to another. The terminal can be very busy for a few days, and then, almost empty in the following days. Labour arrangements have to be enough flexible to match labour supply to fluctuating demand without producing excessive costs on port operators in case of surplus of workers, and without compromising turnaround times and schedules of vessels in case of operators shortages. It is clear that labour arrangements and working practices in manned CTs play a crucial role in the general productivity of the terminal and, consequently, in the time spent in port by vessels, which is one of the most important determinants of port performances and competitiveness.

In particular, interviews with several terminal experts during these years of research have revealed that, in the context of the operational management of workforce, one of the main difficulties from the point of view of terminal operators appears to be the insufficient flexibility allowed by labour regulations and the consequent limited freedom in the daily management of HRs, which instead would require greater flexibility in response to the traditional uncertainty of terminal activities.

Labour flexibility is one of the most sensitive themes in the social dialogue between employer's organisations, which traditionally strive for a greater flexibility, and trade unions, which try to oppose it instead.

Several measures can be taken to improve labour flexibility in CTs. As stated by Notteboom [2010], so far, the most common way to improve flexibility has probably been

[32] The average hourly cost of labour in Egyptian and Moroccan ports is much lower than in Italian ports: 22,1€/h in Italian ports, 3,1 €/h in Moroccan ports and 1,9 €/h in Egyptian ports [Eurispes, 2011].

the introduction of costly bonus systems for irregular working hours. However, in this chapter we try to investigate how flexibility improvements can be achieved with a better use of internal resources by making slight changes in current labour arrangements. We try to investigate the effects of a greater labour flexibility in the management of HR analysing the specific case of Italian CTs. To do so, regulations on Italian dock labour are analysed and a scenario corresponding to the current work organisation at Italian CTs is built. We then compare this scenario to five alternative scenarios, representing five alternative policies on port labour flexibility. Alternative policies are constructed by hypothesizing an increase of daily working flexibility and/or by introducing a new type of labour flexibility, called mini-flexibility.

The simulation of the daily allocation of operators resulting from each scenario is performed through the use of our model for the optimal daily allocation of dockworkers, while the cost scheme described in Chapter 4 is used to estimate the cost effects on vessels' operation delays that result from the manpower allocation of each tested scenario.

The chapter is then organised as follows. Section 2 presents a brief discussion about flexibility issues and port labour regulations in EU member States. Section 3 proposes an overview of Italian regulations concerning port labour. Moreover, this section provides a description of the organisational structure of manpower management, which is currently used in Italian CTs. This is followed by section 4 which analyses the main problems related to the current management of resources in CTs. Section 5 proposes some changes in labour flexibility with respect to current regulations. In section 6, alternative scenarios of labour flexibility are presented and tested. Finally, concluding remarks are made in section 7.

6.2 Flexibility issues and EU port labour regulation

As widely discussed in previous chapters, the main problem in workforce planning in CTs is the uncertain labour demand related to the difficult and imprecise forecasting on the arrival times of vessels [Fancello *et al.* 2011]. Despite the schedules, vessels can delay for many reasons, but, once they are at the port, there are always strong pressures to have them handled as soon as possible. A flexible supply of labour is necessary to perform handling operations when they are effectively required. Specific legal and organisational arrangements in managing the workforce are needed to cope with the specificity of port activities.

Flexibility in port labour may have several faces (e.g. overtime hours, casual workers, multi-skilling, flexible shifts, etc.) but the opportunity to implement them depends on specific labour regulations to which the terminal is subject. In some ports, for instance, cargo-handling companies enjoy numerical flexibility, whereas in other ports more stringent regulation requires cargo-handling companies to employ all their workers on a permanent basis, and other ports combine the benefits of direct employment with numerical flexibility [Barton and Turnbull 2002]. In some ports multi-skilling is allowed while in others is not, some ports may employ casual workers to face demand peak while others do not.

As pointed out by Van Hooydonk [2013], in many European ports, labour rules are characterized by restrictions and restrictive working practices that may impact negatively on terminal efficiency and competitiveness. The main problem is that these restrictions are not the same in all EU States. Moreover, sometimes differences may also occur among ports within the same country. Some countries have developed specific port labour regulations, while others have not, and apply general labour regulations to the port area. Some countries have restrictive regulations on port labour, while others are almost restriction-free. It is quite troublesome to asses in an objective way the current status of port labour regime in Europe, as "*…this is a sector traditionally full of taboo, specificity and also subjectivity*" [Van Hooydonk, 2013]. Port labour systems in EU countries differ widely: in their regulatory set-up, in their operational set-up, in their acceptance among social partners, port authorities and port users [Katsarova, 2013].

For many years the European Commission has been trying to develop a policy framework common for all EU ports, but without success: in the last decade, Commission proposals have been rejected by the European Parliament twice[33]. Today, port policy is governed by National legislation and it is characterized by different port labour regimes. Given the important differences existing among EU countries in the area of port labour, it is not possible to provide a general description of the current status of port labour regime applicable to all countries. Existing differences and peculiarities make it necessary to carry out specific analysis for each country. The existing literature shows some attempts in this direction. Barton and Turnbull [2002] analysed labour regulation in Belgian, French and British ports according to three main criteria: the control of labour supply, the mobility of labour and a guaranteed income for dockworkers. Saundry and Turnbull [1999] compared labour regulation in Spanish and British ports by looking at the employment system adopted. Notteboom [2011] analysed dock labour systems on North-West European ports

[33] Unions have played a key role in the rejection of the two proposals since dockworkers were strongly opposed to them [Katsarova, 2013].

recognising the differences in the way that the various labour systems try to provide an answer to market needs in terms of flexibility, productivity, quality and cost efficiency of dock workers. A recent survey on port labour regulation has been provided by Van Hooydonk [2013], who describes, mainly from a legal perspective, the current port labour regime in 22 maritime EU member States focusing on three aspects of the port labour system: the organisation of the labour market, qualification and training, health and safety.

In this application, we investigate the Italian case. Next paragraph analyses port labour regulations in Italian terminals, focusing in particular on the operational aspects linked to labour flexibility deriving from the application of current labour arrangements.

6.3 The Italian legislative framework

The Italian legislative framework in the area of port labour consists of:

- The Law n. 84/1994[34];
- The Legislative Decree n. 66/2003;
- The National Collective Bargaining Agreement[35] for dock workers (NCBA);
- Second-level Agreements (specific for each port).

The Law 84/1994 is, in Italy, the main regulatory reference in the port area. It has been developed with the aim of reorganising the whole port legislation, in order to recover the competitiveness gap of the Italian port system. The Law 84 has represented for Italian ports the breaking point between an essentially public model of the labour organisation, in which the only reference entity for the port labour was the *Compagnia Portuale* (Dockers' Company), that had overall responsibility for the organisation of the labour force and for carrying out port operations, and a new private model of labour organisation, in which private enterprises with their own workforce can provide port labour. Law 84 has allowed switching from a monopolistic system of port labour to one based on competition, in which there is also the possibility for port firms to resort to temporary labour (authorized pools of dockworkers) to cope with demand uncertainty [ISFORT 2010]. The procedures for the use of temporary labour have to be defined by single ports by means of second level agreements.

[34] Law 28/01/1994, n. 84: Reorganisation of port legislation.
[35] A Collective Agreement is a legal contract, specifying terms and conditions of employment, between an employers' association and trade unions representing workers in the area.

The Legislative Decree 66/2003 is the general norm for the labour organisation in all employment sectors in Italy. It defines the following key points:

- The regular working time is established in 40 hours per week;
- The average duration of working time (regular and overtime) may not exceed 48 hours per week, calculated on a quarterly basis;
- The minimum daily rest period is fixed in 11 consecutive hours every 24 hours;
- The maximum amount of overtime work is fixed in 250 hours per year.

While recognising the special nature of port labour, to account for technical or organisational reasons, the Legislative Decree confers on Collective Agreements the possibility of establishing the maximum weekly on-duties of each worker and defining additional flexibility by extending up to 52 weeks the reference period to calculate the average duration of working time (daily and weekly).

The NCBA in place in Italy is the *NCBA for dock workers 01/01/2009 - 31/12/2012*. It regulates labour relations among terminal operators, port authorities, port companies and dock workers (as defined by the Law 84/94 and its amendments). The NCBA sets out a series of instructions for the specific activity of organisations operating 24h/7d, such as CTs. The duration of the standard weekly working time is established in 36 hours for 24h-shift-workers and for the staff of external firms authorized to provide temporary port labour. The weekly working time can be distributed on 5 or 6 days a week (the decision is referred to second-level agreements). In order to provide an answer to the uncertain nature of terminal activities, the NCBA has introduced the contractual institute of flexible service, allowing a maximum of six flexible services per month to each operator. The contractual institute of flexible service is studied for organisations, such as CTs, that plan their work on the basis of a multi-period programming (usually annual or monthly) of working shifts. Because of the uncertainty of work demand, the multi-period programming assigns, for each day, workers in "fixed" service and workers in "flexible" service. A worker in fixed service in a given day is already assigned to a specific shift on that day, while a worker in flexible service knows he will have to work on that day, but his working shift will be provided only later, with a reasonable notice time. The definition of the notice time is referred to second-level agreements of each port, in most cases the notice time is fixed at 24 hours.

On the basis of regulations concerning port labour, Italian CTs have organised their workforce according to the two different planning levels that we have extensively described in Chapter 2: long-term plan and short-term plan. As already stated, the long-term plan consists of a sequence of workdays and rest-days for each terminal worker ("internal worker") and it is typically performed once a year, according to contractual clauses only. Internal workers in a day may be in fixed or flexible service. According to current regulations, workers in flexible service cannot exceed the 10% of the total amount of internal workers available in that day. Multi-skilling is allowed for internal workers according to a system of qualification based on certification and training.

The short-term plan (24/48 h) is a refinement of the long-term one and it is typically performed 24 hours in advance of the planned work day, when the work demand data is more precisely known. The short-term plan takes the workers in fixed service from the long-term plan and then determines the shifts of workers in flexible service. Moreover, when internal workers are not sufficient, in order to face the work demand peak, it is possible to employ a limited number of *external workers*, coming from pools authorized to provide temporary labour, to perform low level tasks (see Chapter 2).

Therefore, three main instruments of flexibility are currently available in Italian CTs to cope with the fluctuating demand:

- Multi-skilling of internal workers;
- Recourse (limited for quantity and permitted tasks) to temporary labour, also called external labour;
- Flexible shifts of internal workers (maximum 10% of internal operators available per day).

In addition, there is always the possibility to resort to the costly overtime, which on average costs between 30 and 50 per cent more than the regular working time. Due to its high costs, terminal operators try to limit the overtime, resorting to it only when absolutely necessary; overtime hours generally represent less than 20 per cent of total work hours performed in a port.

6.4 Issues of the current manpower planning

The shift-scheduling of dockworkers according to the two planning levels (long-term and short-term) presents several problems. In fact, the long-term plan, which is absolutely binding to the next level (short-term), is performed when the effective work demand of the day is almost unknown. A shift scheduling ignoring demand data and considering only labour agreements and contractual clauses has clear limits of efficiency and does not allow a good match between the work demand and the work supply available in the day. The consequences of the long-term plan rigidity can be summarised in the three typical situations described below. Each situation is followed by a description of its resulting effects according to the current Italian port labour arrangements.

1. *On the planned day, more workers than the actual demand are assigned;*

   The CT is operating below its potential: workforce supply is in excess compared to the actual need of the day. The effects of manpower surplus vary according to the type of worker in surplus:

   - If the worker in surplus is a worker in flexible service, his working day is transformed into a rest day. The rest day may compensate overtime hours performed by the worker in the quarter of reference, if any;
   - If the worker in surplus is in fixed service, at least theoretically, he will have to be paid for a normal working day, regardless of the fact that he has worked or not.

2. *On the planned day, less workers than the actual demand are available;*

   The workforce supply is undersized compared to the actual need of the day. The manpower office assigns all internal available workers and, when possible, external ones. The purpose is to fulfil at least the activities with the highest priority. Part of the activities scheduled for the day cannot be performed. There are two possibilities of intervention:

   - To fulfil part of the activities through overtime work, but a higher cost per hour must be paid;
   - To postpone backlogs to later shifts with inevitable operation delays for vessels.

3. *On the planned day, the allocation of workers on shifts inherited from the long-term plan does not match demand and supply, although the total amount of available workers would be sufficient to cover the actual demand of the day;*

   In other words, in some shifts the workers assigned are more than needed, while in other shifts they are not sufficient. The little flexibility of the long-term plan does not allow an optimal use of the available workers in the planned day. The terminal must resort to overtime in order to face shortages in some shifts, despite surpluses occurring in other shifts. In fact, workers in fixed service cannot be assigned to other shifts due to adopted shifting policies.

As seen, the rigidity of the long-term plan may lead to different situations, which are all characterized by a sub-optimal use of resources. However, if in the first situation the effects of this sub-optimal use affect only the terminal operator which has to bear the higher cost of an inefficient allocation, in the remaining situations the occurrence of shortages does not allow to fulfil the demand of the day, resulting in costly delays also for shipping operators (see Chapter 4).

Shortages in terminal activities may have various reasons: they can derive from unexpected reductions in the number of available workers, due to strike or sick leave for instance, or, more frequently, from unforeseen demand peaks. Whatever the specific reason, shortages always derive from an unsatisfactory matching between the work demand of the day and the work supply available in the same day. In fact, the complexity of the relationship between work demand and work supply would require a high labour flexibility, which is not always achievable.

Labour flexibility in port activities can be realised in several forms [Notteboom 2010]:

- Active and passive flexibility in working hours. The former implies that the employer establishes schedules, whereas the latter gives a lot of initiative to the employees and is more common in ports with a large amount of occasional workers.
- Flexibility in tasks, which allows port workers to be used for different types of tasks (multi-skilling) according to their qualifications. Nowadays, a growing number of CTs organise good training programmes, but there are still terminals where workers are poorly trained. When workers are multi-skilled, it is unlikely that shortages and surpluses of workers occur at the same time [Saundry and Turnbull 1999]; this is a particular situation in which labour demand requires operators with specific skills, but the operators available do not have the required competences.
- Flexibility in the size of working teams. It allows varying the size of the gangs to match the desired productivity per hour.
- Flexibility in labour quantity. It refers to the possibility to adapt the size of the workforce to the amount of work that needs to be done.

The latter is probably the most important form of flexibility for a good business operation in CTs, when the demand peaks that are not included in the long-term plan can occur when the daily workforce management is being planned.

Considering the current organisation of manpower management in Italian ports, in this study we want to evaluate the effects of a greater flexibility at the operational level, by increasing the share of the flexibility allowed in the long-term plan for each internal worker. The fundamental idea is that a greater flexibility within the pool of internal workers would ensure a more efficient use of terminal resources, reducing the need to resort to the more expensive overtime and external work.

6.5 Changes in labour flexibility policies

We hypothesize three ways to increase the flexibility allowed in the long-term planning:

1. *An increase in the share of traditional monthly flexibility for each worker.*
   Every worker has a higher number of days in flexible service during the month.
   Change scenarios will be constructed by increasing the number of available workers in flexible service in the planned day, while maintaining the same amount of total available workers.
2. *The introduction of a new type of flexibility: the so-called mini-flexibility.*
   With the introduction of the contractual institute of the mini-flexibility, a worker in mini-flexible service that looks at a particular day in the long-term plan (monthly/annual) does not know the exact working shift, but knows for sure whether it will be a night-shift (19-07) or a day-shift (07-19). The partitioning of 4 shifts into two typologies (night and day) allows us to take into account the differences perceived by workers for what concerns the attractiveness of a shift, and at the same time, to consider the different hourly cost for each shift: night shifts cost on average 30% more than day shifts.
   Compared to traditional flexibility, mini-flexibility allows the reduction of discomfort for workers. In fact, a worker who is in mini-flexible service in a given day, has the opportunity to know in advance, by looking at the long-term plan, his likely working shift (night or day). On the other hand, mini-flexibility allows a wider leeway to planners who plan the manpower allocation in the short term, allowing a better matching between demand and supply for each shift.
   Appropriate change scenarios will be constructed by choosing a share of workers in mini-flexibility among the internal workers available in the planned day.

3. *The simultaneous use of a quota of traditional flexibility and a quota of mini-flexibility.* Appropriate change scenarios will be constructed by choosing at the same time a share of workers in mini-flexibility and a share of workers in traditional flexibility among the internal workers available in the planned day.

6.6 Experimental tests

In this section we aim at simulating the effects that alternative scenarios of labour flexibility have in the daily management of workforce. We use our optimisation model (see Chapter 3) to determine the optimal daily manpower allocation that results from the scenario representing the current organisation of port labour and five alternative scenarios representing changes in flexibility policies. We perform our experimentation considering a set of real instances derived from normal working days of a Mediterranean CT. Data used in this application are as follow:

- the working day is divided into four shifts of six hour each;
- the work demand is expressed in terms of number of gangs needed in each shift to perform vessel and housekeeping activities;
- the vessel gang is made up of 1 quay craner (qc), 2 yard craners (yc) and 3 truck trailer drivers (tt) while the housekeeping gang has 2 yard craners (yc) and 3 truck trailer drivers (tt).
- 88 internal operators are available in the day (the share of operators in fixed and flexible service changes from scenario to scenario). The set of internal operators, their costs, main tasks and shifts according to the long-term plan is taken from granted;
- 12 external workers are available in the day, their unitary cost is taken for granted by the terminal. These workers are supposed to perform truck trailer driving tasks only;
- the productivity index p_{ijkz} as well as the index of activity complexity a_z are supposed to be constant in this application;
- the priority g_z of vessel operations is supposed to be twice the housekeeping priority;
- the cost of shortages for the different tasks is supposed to be twice the average hourly cost of each task.

To illustrate work demand data we refer to Table 6.1 and Table 6.2, which have the same organisation as Tables 3.2 and 3.3 in Chapter 3. Table 6.1 shows the work demand of the day in terms of gangs required in each shift, while Table 6.2 shows the same amount of work demand in terms of operators needed for each task in each shift. For instance at shift 2, 8 *yc* are requested to serve vessels and 2 for housekeeping. Since *qc* are not involved in housekeeping activity, their demand is denoted by " - ". The last row shows the total number of workers required in each shift and in the whole day.

Table 6.1 – Work demand of the day.

	Shift 1	*Shift 2*	*Shift 3*	*Shift 4*
VG – Vessel Gangs	4	4	2	6
HG – Housekeeping Gangs	0	1	0	1

Source: author.

Table 6.2 - Work demand of the day, in terms of number of requested workers.

	Shift 1		*Shift 2*		*Shift 3*		*Shift 4*		*Day*
	VG	**HG**	**VG**	**HG**	**VG**	**HG**	**VG**	**HG**	
Quay craners (qc)	4	-	4	-	2	-	6	-	16
Yard craners (yc)	8	0	8	2	4	0	12	2	36
Truck trailer drivers (tt)	12	0	12	3	6	0	18	3	54
Total workers required	24		29		12		41		106

Source: author.

The workforce available on the day is described in Table 6.3. The first column shows the number of available internal workers, divided into workers in fixed (fix) and flexible (flex) service, the second column shows the number of external workers, while the third column shows the total amount of workers available on the day.

Data in Table 6.3 are used to generate the first scenario, which is denoted as *Scenario 0*. Scenario 0 corresponds to the current work organisation at the terminal where flexible workers in a day are about 10% of the total internal workers available on the day.

Table 6.3 – Available workforce in the day – Scenario 0.

Internal Workers		**External workers**	**Total workers at hand**
Fix	**Flex**		
80	8	12	100

Source: author.

Looking at the supply and demand data of the day, we observe that the number of available workers (100 operators) is slightly undersized compared to the actual work demand (106 operators). We use our optimisation model to determine the optimal assignment of operators for the *Scenario 0*. In order to detect possible manpower surpluses, original constraints (1) and (2) described in Chapter 3 are modified as follows:

$$\sum_{i \in N} x_{ijkz} + v_{jkz} + u_{jkz} \geq ns_{jk} \cdot s_{jz} \qquad \forall j \in J, \forall z \in S, \forall k \in K$$

$$\sum_{i \in N} x_{ijkz} + v_{jkz} + u_{jkz} \geq nh_{jk} \cdot h_{jz} \qquad \forall j \in J, \forall z \in H, \forall k \in K$$

Results of the allocation associated with *Scenario 0* are presented in Table 6.4. What would be expected from the allocation is the assignment of the 100 available workers and the report of 6 shortages. However, results show something different. Table 6.4 shows for each shift the number of internal and external workers assigned, the number of shortages occurring for each task (*qc*, *yc* and *tt*) and the number of manpower surpluses, if any. The surplus is defined as the number of workers in excess in a shift with respect to the actual work demand of the shift.

For instance, 20 internal workers are assigned at shift 3. Since the total work demand at shift 3 was 12, a surplus of 8 workers occurs.

Table 6.4 – Assignment Results – Scenario 0.

	Type of worker		Shift 1	Shift 2	Shift 3	Shift 4	Total
Scenario 0	- INTERNAL		20	24	20	24	**88**
	- EXTERNAL		2	-	-	10	**12**
	- SHORTAGES	- Vessel Gangs	2 yc	-	-	2yc	**4yc**
		- Housekeeping Gangs	-	2yc+3tt	-	2yc+3tt	**4yc+6tt**
	- SURPLUS		-	-	8	-	**8**

Source: author.

The last column of Table 6.4 shows the overall work balance of the day. Despite assigning all 88 internal workers and all external ones, shortages detected are not 6 but 14 (4 *yc* in vessel gangs and 4 *yc* plus 6 *tt* in housekeeping gangs). In fact, 8 workers who were in fixed service at shift 3 cannot be assigned to other shifts, as rigidly assigned by the long-term plan to shift 3 in which, however, they are not employable. As a consequence, the terminal has to face a shortage of 14 workers, despite a surplus of 8 workers at the third shift. The detail of the problem instance *Scenario 0* is shown in Appendix 6.

At this stage, the goal becomes to verify how this assignment would change if, while maintaining the same amount of available workers, a greater labour flexibility within the pool of internal workers available in the day was allowed. For this purpose five change scenarios on labour flexibility are proposed. The proposed scenarios are described in Table 6.5.

Table 6.5 – Five Scenarios of change in labour flexibility.

ID Scenario	Internal Workers				External workers	Total available workers
	Fix	Flex	Mini-flex	Total		
Scenario 1	72	16	0	88	12	100
Scenario 2	64	24	0	88	12	100
Scenario 3	60	0	28	88	12	100
Scenario 4	60	8	20	88	12	100
Scenario 5	50	8	30	88	12	100

Source: author.

For each scenario, Table 6.5 shows:

- in the second column, the number of internal workers available on the planned day divided into fixed, flexible and mini-flexible (mini-flex);
- in the third column, the maximum number of external workers available on the day;
- in the fourth column, the total number of workers available on the planned day (internal workers plus external ones).

The total amount of available workers and the number of external workers remains unchanged in all scenarios. In fact, scenarios are constructed varying only the amount of traditional flexibility or introducing a quota of mini-flexibility within the pool of the 88 available internal workers. It is worth noting that the total amount of workers is the same as *Scenario 0*. The 5 scenarios introduced are characterized as follows:

- Scenario 1. The share of workers in traditional flexibility is doubled compared to *Scenario 0*; that is, 72 are in fixed service while 16 are in flexible service out of the 88 available internal workers. *Scenario 1* does not provide workers in mini-flexible service.

- Scenario 2. The share of workers in traditional flexibility is tripled compared to *Scenario 0*; that is, 64 are in fixed service while 24 are in flexible service out of the 88 available internal workers. *Scenario 2* does not provide workers in mini-flexible service.
- Scenario 3. Compared to *Scenario 0* there are no workers in traditional flexibility. *Scenario 3* introduces the mini-flexible service: 28 are in mini-flexibility while the remaining 60 are in fixed service out of the 88 internal workers.
- Scenario 4. It provides a combination of workers in traditional flexible service and workers in mini-flexibility. The 88 internal workers are deployed as follows: 60 are in fixed service, 8 are in traditional flexible service and 20 are in mini-flexible service.
- Scenario 5. Compared to *Scenario 4*, it provides a greater share of workers in mini-flexible service. The 88 internal workers are deployed as follows: 50 are in fixed service, 8 are in traditional flexible service and 30 are in mini-flexible service.

The results of the assignment performed through the optimisation model for the 5 scenarios are shown in Table 6.6, which is organised like Table 6.4.
Looking at the data in Table 6.6, we can observe that, compared to *Scenario 0*, the increase in the share of labour flexibility produces a more efficient use of resources in all the scenarios tested. This more efficient use is confirmed by a reduction in the number of workers in surplus and by lower manpower shortages occurring in the planned day.
Data details of Scenarios from 1 to 5 are reported in Appendices from 7 to 11, respectively.

Table 6.7 shows the effects of the assignment produced by each scenario in terms of operation delays and the related costs when no actions are timely taken to correct the deficiencies. The effects of each scenario are calculated as a function of manpower shortages occurring in vessel gangs during the planned day. The operation delay is the time for a vessel gang to work on containers that have not yet been handled due to manpower shortages. The estimation of the additional time required to complete operations and the related costs are made on the basis of considerations in Table 4.4 and 4.5 in Chapter 4. Since we are estimating the extra-time required to complete operations on vessels, manpower shortages in housekeeping gangs are here neglected. Operation Delay Costs (ODC) are calculated for all the three types of container vessels already considered in section 4.3. For instance, looking at the Table 6.6, 3 truck trailer drivers lacked in *Scenario 2*. This manpower shortage corresponds to 132 containers not handled and to an operation delay of six hours, i.e. a vessel gang needs six more hours to complete operations on the vessel. This operation delay results in a cost of 7.425 USD for a Panamax vessel, 9.962 USD for a Post Panamax vessel and 12.443 USD for a Post Panamax Plus, according to cost values listed in Table 6.7.

In addition, an estimation of the cost related to manpower surpluses in the planned day is provided in Table 6.8. As seen before, the surplus in a shift of a worker in fixed service produces additional cost for the CT. In fact, at least theoretically, that worker should be paid even if he does not work in that shift. The estimation of the cost associated to the manpower surplus in the planned day has been done considering an average hourly labour cost of 29 USD/h per worker. For instance, 6 workers are in surplus in *Scenario 1*, the corresponding Manpower Surplus Cost for the terminal amounts to 1.044 USD.

Table 6.6 - Assignment Results – Scenarios 1, 2, 3, 4 and 5.

Scenario	Type of worker		Shift 1	Shift 2	Shift 3	Shift 4	Total
Scenario 1	- INTERNAL		18	23	18	29	**88**
	- EXTERNAL		5	1	-	6	**12**
	- SHORTAGES:	- Vessel Gangs	1yc	-	-	4tt	**1yc+4tt**
		- Housekeeping Gangs	-	2yc+3tt	-	2yc	**4yc+3tt**
	- SURPLUS		-	-	6	-	**6**
Scenario 2	- INTERNAL		19	22	16	31	**88**
	- EXTERNAL		5	5	-	2	**12**
	- SHORTAGES:	- Vessel Gangs	-	-	-	3tt	**3tt**
		- Housekeeping Gangs	-	2yc	-	2yc+3tt	**4yc+3tt**
	- SURPLUS		-	-	4	-	**4**
Scenario 3	- INTERNAL		15	29	15	29	**88**
	- EXTERNAL		6	-	-	6	**12**
	- SHORTAGES:	- Vessel Gangs	3yc	-	-	1tt	**3yc+1tt**
		- Housekeeping Gangs	-	-	-	3yc+2tt	**3yc+2tt**
	- SURPLUS		-	-	3	-	**3**
Scenario 4	- INTERNAL		16	25	15	32	**88**
	- EXTERNAL		6	2	-	4	**12**
	- SHORTAGES:	- Vessel Gangs	2yc	-	-	-	**2yc**
		- Housekeeping Gangs	-	1yc+1tt	-	2yc+3tt	**3yc+4tt**
	- SURPLUS		-	-	3	-	**3**
Scenario 5	- INTERNAL		16	28	12	32	**88**
	- EXTERNAL		6	-	-	6	**12**
	- SHORTAGES:	- Vessel Gangs	2yc	-	-	1tt	**2yc+1tt**
		- Housekeeping Gangs	-	1tt	-	2yc	**2yc+1tt**
	- SURPLUS		-	-	-	-	**-**

Source: author.

Table 6.7 – Operation Delays and related Costs for Scenarios 0, 1, 2, 3, 4 and 5.

Scenario ID	Manpower shortages	Containers not handled [TEU]	Operation Delay [h]	ODC - Operation Delay Cost [USD]		
				Panamax	Post Panamax	Post-Panamax Plus
Scenario 0	4yc	264	12	14.850	19.924	24.886
Scenario 1	1yc+4tt	242	11	13.618	18.260	22.814
Scenario 2	3tt	132	6	7.425	9.962	12.443
Scenario 3	3yc+1tt	242	11	13.618	18.260	22.814
Scenario 4	2yc	132	6	7.425	9.962	12.443
Scenario 5	2yc+1tt	176	8	9.904	13.280	16.592

Source: author.

Table 6.8 – Daily Cost related to manpower surpluses for Scenarios 0, 1, 2, 3, 4 and 5.

Scenario ID	Number of workers in surplus	Manpower Surplus - Daily Cost [USD]
Scenario 0	8	1.392
Scenario 1	6	1.044
Scenario 2	4	696
Scenario 3	3	522
Scenario 4	3	522
Scenario 5	-	0

Source: author.

Looking at the data shown in Tables 6.7 and 6.8 we observe that, compared to *Scenario 0*, the increase in the share of traditional flexibility, or the introduction of mini-flexibility, produces lower manpower shortages, lower additional costs and, thus, a better use of the available workers in all the scenarios tested.

The increased labour flexibility in the long-term plan allows a more efficient allocation of manpower in the short-term with positive economic effects for both the terminal operator and the shipping company.

It is important to note that the analysis performed in this application is referred to a single day of terminal activity. The cost values involved will assume a more relevant weight if compared to what may occur in a whole year of activity of the terminal.

6.7 Conclusion

It is well known that labour regime has a fundamental role in determining both day-to-day levels of efficiency and the long-term dynamics of competitiveness among ports, especially in manned CTs. In particular, labour flexibility is one of the most important

determinants of resulting performances in a system characterized by uncertain and fluctuating demand, as the port system is.
However, port labour arrangements may vary considerably among ports. In some CTs, strict labour regulations and insufficient labour flexibility can prevent an optimal use of the available resources with negative impacts in terms of loss of efficiency, with increased operating costs and a general loss of competitiveness compared to other competitors operating under more permissive labour regulations.

In this chapter we wanted to investigate how flexibility improvements can be achieved with a better use of internal resources, making slight changes in current labour arrangements. We have focused on the specific case of Italian CTs and we have analysed their labour regulation and labour arrangements. Afterwards, several change scenarios on port labour flexibility have been proposed with the aim of illustrating how a greater flexibility in port labour may produce a more efficient use of the available resources and a decrease in operating costs. A scenario corresponding to the current labour arrangements in Italian ports was compared to five alternative scenarios, which are constructed by increasing the share of daily working flexibility and introducing a new type of labour flexibility, called mini-flexibility. The effectiveness of each scenario was evaluated with the use of our optimisation model for the daily allocation of dock workers in CTs. The effects of the manpower allocation resulting from each scenario have been compared in terms of observed manpower shortages, vessel operation delays and costs related to consequent extra-time spent by vessels in port to complete loading operations.

The results of the experimentation have shown that increased labour flexibility among internal workers can produce a better use of resources and a significant reduction in operating costs related to delays in port operations. In fact, lower manpower shortages and shorter service times occur when a greater labour flexibility is used. Consequently, promoting a more efficient use of resources by adopting a greater labour flexibility can help to reduce the competitive gap of Italian terminals with respect to other competitors working under more lax labour regulation.

Further considerations before concluding the chapter. We have analysed alternative scenarios of labour flexibility, but our aim was not to determine the best scenario; in fact, this task would have required additional considerations on labour policies that are however beyond the purpose of this study. The aim was rather to achieve a better understanding of the role of flexibility in port operations and to provide objective elements that might help the on-going discussions about the importance of labour flexibility in port areas and the

opportunity to implement changes on flexibility policies, which today appear to be limiting for some CTs.
Labour flexibility has always been a very sensitive issue in port area and, not surprisingly, it is one of the most common themes in social dialogue between employers' organisations and trade unions. The first traditionally strive for a greater flexibility, the latter try to oppose to it and ask for new benefits in exchange. Most of the times these opposite needs lead to long disputes within the ever animated dialogue between terminal operators and unions, with negative effects on port activity, especially when conflicts turn into strikes, work stoppages or other forms of industrial actions.

Furthermore, a new issue that will probably have serious impact on port labour is now emerging in the CT area. The last 20 years have seen the introduction of the automation in terminal activities [Henesey *et al.* 2009]. Several European CTs have started making investments in automation equipment with the main aim to reduce the high cost of labour and, probably, put aside restrictions of labour regulation. CTs already implementing automation technology have reported significant savings[36] and a general improvement in efficiency. Changes in labour regimes are necessary to compete with automation and to maintain the role of ports as job generators. It is clear that doing nothing is not a viable scenario today. The greatest risk is that, in the absence of interventions in the short-term, the loss of competitiveness that Italian CTs have demonstrated in recent years will result in a reduction of terminal activities with negative economic effects on the employment front and the territory in general.

[36] According to the estimates, labour costs for moving containers at the Rotterdam Maastvalte II terminal will fall by two-thirds as a result of new investment in automation equipment (source: Port Finance International, 2012).

CHAPTER 7*

European Container Terminal Operation Concepts: Strategic Determinants and Policy Options

7.1 Introduction

CTs make use of different Operating Systems (OS) for the management of the yard and of transportation of containers. The decision of what system to use is a strategic decision that is based on factors such as cost of land, available technology, economies of experience and the relative productivity of labour. With the appearance of automation in CTs in the last two decades a new set of operational alternatives have become available to operators. If on the one side the pursuit of increasing efficiency and reducing labour cost has pushed CTs to investigate automation options, on the other side many CTs still prefer more traditional operational concepts as a result of system reliability and labour flexibility issues. These issues have been so far investigated almost exclusively from a technical point of view, making use of operation research methods and advanced modelling, but limited research has been performed in the area of the strategic determinants of the choice of terminal OSs. This is due to the fact that typically such choices are related to factors and issues that are difficult to research for the lack of data, e.g. the costs of land in ports, or given their sensitive nature, e.g. labour productivity in ports. Such determinants nonetheless have important consequences on the success of the CT and critical policy

* **This Chapter is mainly based on Acciaro and Serra [2014].**

implications. Considering the increasing competition among European ports and the critical role of container transport in sustaining the competitiveness of maritime supply chains, more empirical studies can provide substantial value to the debate on port policy and terminal management.

This chapter aims at empirically investigate the determinant factors behind the choice of the OSs. In particular, we want to verify the possibility of establishing an empirical relation between the labour regime existing in a terminal, evaluated in terms of labour cost and labour regulation, and the preference for automated models or, more in general, for less labour intensive concepts.

This application is among the first attempt to empirically analyse the determinants of the CT operation concepts employed in European terminals. We have compiled a database comprising 65 European CTs whose major determinants of the operation concepts have been quantified. The use of multinomial logit regression techniques provides interesting insights on what strategically motivates the choice of a specific operating model instead of another, in order to investigate managerial and policy implications.

The rest of the chapter is structured in the following way: section 2 is a critical analysis of the existing terminal operating models used in Europe, with a specific focus on the advantages and disadvantages of each; section 3 describes the data used and the econometric model that is tested in the empirical section; section 4 describes the model results and some management implications. Finally, section 5 concludes.

7.2 Terminal operating models

In choosing a certain OS a port operator has to decide among a variety of possibilities: manned or automated systems, Rubber Tyred Gantry cranes (RTG), Rail Mounted Gantry cranes (RMG), pure Straddle Carriers (SC), etc. A question arises: which factors are determinant for the decision of an OS rather than another?

The decision concerning the adoption of a particular OS is a strategic one and it is based on various factors. So far this issue has been investigated almost exclusively from a technical point of view (an updated review can be found in Stahlbock and Voß [2008]), whereas there is a lack of studies regarding the strategic determinants that lead to the choice of one OS.

It is fair to say that many factors can affect this decision. These factors may vary from terminal to terminal and even among CTs within the same port, although factors driving the choice are always of economic nature.

Traditionally, the main determinants of the OS choice have been identified as space availability, stacking capacity and equipment costs. Extensive literature deals with these issues [Steenken *et al.* 2004, Vis and Harika 2004, Stahlbock and Voß 2008, Wiese *et al.* 2011]. Broadly speaking, in CTs where space is restricted or too costly, stacking capacity is a determinant factor in the OS choice. In these terminals, RTGs/RMGs are typically adopted because of their high stacking ability. Whereas, in other CTs where space availability is not a problem, SCs are more popular because of their lower purchase cost and high flexibility in operations. Within these general considerations concerning space availability and stacking capacity, several handling systems can be adopted. Therefore, if at a first stage physical constraints related to availability of space and to the achievable yard capacity lead to exclude (or include) some handling options, in a second stage other determinant factors come into play in the choice of the most suitable OS. These determinants can range from the price of industrial lands to the labour regime existing in the area, from the typology of the operator who runs the CT to the nature of the traffic served.

7.2.1 Common Terminal Operating Systems

The right selection of the OS is a key factor for a successful terminal. It is not possible to talk about a universal model that can adapt successfully to all terminals' configurations; conversely, there are different layouts and OSs that can fit better or worse depending on the various criteria and objectives that drive the terminal's choice. Extensive literature describing terminal OSs exists [see, among others, Brinkmann 2011, Gunther and Kim 2006]. This section gives a short overview of the most common OSs adopted in European CTs.

Indirect Transfer System based on Rubber Tyred Gantry cranes – RTG System.

It is a largely standardized system quite common on large and very large CTs. The Ship-To-Shore (STS) crane places the box on a Truck Trailer Unit (TTU) that transfers it to the storage area where the RTG, which moves on rubber-tyred wheels, stacks it in blocks. The RTG system is more flexible in operations than the RMG system because of the lack in fixed rail-track; it is space-efficient because of the high stacking capability (up to

7-high) and the block stacking (up to 8 rows plus a truck lane for TTUs), and it is fast in operations because long travelling distances are covered by TTUs. RTG system can achieve yard capacity of approximately 1.000 TEUs per hectare. 2-3 RTGs and 4-5 TTUs are required per STS crane under normal operating conditions.

Indirect Transfer System based on Rail Mounted Gantry cranes – RMG System.

Unlike RTGs, RMGs travel on fixed rail-track with cantilever outside the portal of cranes. The RMG system provides fast operation and high-density storage (stack up to 1 over 7 high and 12 containers wide) with yard capacity that can exceed 1.000 TEUs per hectare. About two thirds of all RMGs in the world can only stack of 1-over-3 high, with just 14 per cent going 1-over-4; however, the share of 1-over-5 units going greater and greater [Huang and Chu 2004]. RMGs are easier to automate than RTGs, more durable and reliable with low maintenance costs; however they are more expensive to install and less flexible in operation because of rail mountings [Brinkmann, 2011], with high disturbance of terminal activities in case of equipment failures.

Indirect Transfer System based on Reach Stackers/Fork Lifts (RS/FL) and TTUs – TTU System.

In the TTU system the STS crane places the box on a TTU that transfers it to the storage area where RS/FLs stack it in blocks. In small CTs, when distances between quay and yard are really short, RS/FL can also perform horizontal transportation without requiring additional equipment. The TTU system because its versatility is the common choice for small and medium size CTs and for multi-purpose terminals. Its ease of use makes it a good choice for terminals with low-trained workforce. 3-4 RS/FLs and 4-5 TTUs are required per STS crane under normal operating conditions. The RS/FL system allows storage capacity ranging from 350 to 500 TEUs per hectare depending on the high-stacking.

Direct Transfer System based on Straddle Carriers – SC System.

The SC system combines the functionalities of stacking cranes and horizontal transport vehicles being independent from other terminal equipment. SCs are able to directly access the container from the STS crane, transport it in the yard, lift it up (2 or 3 containers high, maximum 4), load/unload trucks or rail cars and move containers. Depending on the way used to transport containers between quayside and yardside, two different SC systems are defined: SC pure and SC relay systems. In the first system, the transfer of containers between quay and yard is performed by SCs, while in the second one by TTUs. SCs have features of high manoeuvrability, flexibility in operation and relatively high speed of movement. The SC system is quite common in medium-large terminals with high throughputs, when high flexibility and accessibility in the yard are required. When a terminal adopts the SC system, the yard is normally arranged in long rows with boxes placed end to end and separated by traffic lanes, allowing a medium stacking density (500 TEUs per hectare stacking 2-high, 750 TEUs per hectare stacking 3-high). 4-5 SCs are required per STS crane under normal operating conditions. Thus, compared to other systems which use TTUs, labour cost in SCs system is lower because of the reduced number of vehicles deployed.

Automated systems

Some new OSs present characteristics of full or partial automation of the yard. In these systems only QCs are still manually operated; the horizontal transfer, the storage and retrieval of containers in the yard are performed in whole or in part by automated equipment. A strict separation between the automated area and the manned area is always required for safety reasons.

In CTs that make use of automated transport vehicles the transfer of containers between quay and yard can be performed through two types of automated equipment: Automated Guided Vehicles (AGV) and Automated Lifting Vehicles (ALV). The main difference between them is that the second ones are capable of lifting containers from the ground by themselves. Automated Stacking Cranes (ASC) are used to stack and retrieve boxes in the storage area.

Depending on the level of automation, terminals can be Fully or Semi-automated. Fully automated systems typically use AGVs or ALVs for the horizontal transport of boxes and ASCs for the stacking of boxes in the yard area. In semi-automated terminals only one of these operations is performed by unmanned equipment. Main advantages of automated systems are identified in the high productivity of the horizontal transfer and in lower labour costs compared to traditional systems. On the other hand, such systems are characterized by rigidity in operations, high investment and need for high-trained workforce.

Table 7.1 summarises the main features of the described OSs. In particular, the second column lists the achievable stacking density, the third column reports the number of operators required per QC considering normal operating conditions, while the last columns list the main disadvantages and advantages of each system.

Table 7.1 - Operating Systems.

Operating System	**Stacking Density [TEU/ha]**	**Operators Requirement per Quay Crane**	**Main Disadvantages**	**Main Advantages**
RTG	1.000	2-3 RTG + 4-5 TTU	- Two handover procedures - Disturbance of yard operations by TTs	- Space efficient - Fast in operations - More flexible than RMG - Medium investment cost
RMG	1.000	2-3 RMG + 4-5 TTU	- High investment and capital costs - Two handover procedures - Rigid system - High disturbance in case of RMG failure - Disturbance of yard operations by TTs	- Space efficient - Fast in operations - More durable than RTGs - Easier to automate than RTGs - Medium operating costs
SC	500-750	4-5 SC	- Medium investment and capital cost - High maintenance and energy costs - High area requirement - Slow transfer speed	- SCs cover all kinds of transport - The breakdown of one SC has low impact on the total process - Lower labour cost than TT systems - Flexibility in operations
TTU	350-950	3-4 RS/FL + 4-5 TTU	- Two handover procedures - High manning requirements - High labour cost - Disturbance of yard operations by TTs	- Low investment - Low capital and operating costs
Fully-automated	1000 or more	-	- Very high investment/capital cost - Rigid system - High trained labour	- Very low labour cost - Very high productivity
Semi-automated with AGVs	1000 or more	2-3 RMG	- High investment and capital cost - Rigid system - Well trained labour	- Low labour cost - High productivity of horizontal transport
Semi-automated with ASCs	1000 or more	4-5 TTU	- High investment and capital cost - Rigid system - Well trained labour	- Low labour cost - High productivity of vertical transport

Source: own elaboration based on Brinkmann [2011] and Huang and Chu [2004].

7.2.2 Automation and manually operated systems

In the last two decades, automation has appeared in European port area as a component of the efforts made to achieve improvements in CTs performances and to increase CTs capacity while containing operating costs (AGVs were first introduced in 1993 at Delta CT in Rotterdam) [Ballis *et al.* 1997, Henesey *et al.* 2009]. The reasons to improve terminal handling processes through automation are manifold [Vis 2006, Stahlbock and Voß 2008]: higher capacity, higher productivity, use of time and space to full capacity, higher utilization rate of mechanical equipment and lower labour costs. It is recognised that, among all these factors, the most significant benefit that automation brings is the reduction of labour cost [Brinkmann 2011, Port Finance International 2012]. As already discussed in the first chapters, labour cost represents the main part of the total operating costs of a manned CT [Notteboom 2010, Van Hooydonk 2013]. Nowadays, many European container ports deploy large amounts of dockworkers to comply with labour union demands and strict labour regulation. These factors lead CTs of countries characterized by high labour costs to be at a competitive disadvantage when compared with their competitors, especially with North African ports, that traditionally spend less on manpower and operate under more permissive regulation. It should be noted that the average hourly cost of labour in Egyptian and Moroccan ports is much lower than in European ports: 25 €/h in European ports, 3,1 €/h in Moroccan ports and 1,9 €/h in Egyptian ports [Eurispes 2011]. It is not surprising that automated equipment have been first introduced in German and Dutch terminals, where labour cost is traditionally high and regulation on port labour is quite restrictive. Notwithstanding the achievable labour cost saving, the expected automation boom has not yet happened. So far, only seven CTs in Europe have deployed automated equipment, three of which use fully automated OSs (Europe Container Terminal and Euromax Terminal in Rotterdam, and Container Terminal Altenwerder in Hamburg), while the remaining four use semi-automated systems (Deurganck Dock in Antwerp, BEST Terminal in Barcelona, Noatum Terminal in Malaga and Isla Verde TTI in Algeciras). The most likely reason is that even if labour remains the most significant cost item, there are further factors that must also be assessed when comparing automated models with traditional ones.

In the existing literature we can find a number of attempts to compare terminal handling systems; the results of these studies do not always indicate the same direction. Ballis *et al.* [1997] made a comparison of low volume terminals between a conventional SC system and a fully automated system based on ASCs and AGVs; findings highlight that there are no significant differences between the two systems in the total cost per container and in area requirements; although differences exist in investment cost and personnel required. Cederqvist [2009] compared a traditional RMG and an Automatic Cantilever RMG, concluding that automation is profitable, not only for large ports (> 1 MTEU/year), but also for medium large ports (<0,5 MTEU/year). In his study, automation leads to a reduction of labour requirements with great advantages from a cost perspective but also with advantages in case of scarce skilled labour. Conversely, Nam and Ha [2001] in comparing an automated system to a traditional system looking at cost, productivity and resources, concluded that the conventional system is better than the automated one with respect to both cost and productivity. It should be noted that their application involved Korean terminals, where labour costs are lower; this factor may have acted in favour of the conventional system. Further evaluation on different automated CT concepts can be found in Liu *et al.* [2002] and Ioannou *et al.* [2000].

Considerations on the traffic volume required to absorb the high investment cost, on the availability of space and on the acceptance of new technologies by labour unions need to be evaluated when assessing the choice for automated OS.

7.3 Data and methodology

7.3.1 Data description

We have compiled a database with the technical characteristics, the throughput and a set of port and country specific indexes, aiming at summarising the specific characteristics of the OSs of CTs. The sample includes 65 European CTs mainly located in the Mediterranean area and in the North-West area. The selected CTs are distributed across 26 major container ports and 12 European countries. The analysis focuses on CTs instead of container ports as important differences may occur even among terminals within the same port in terms of throughput, infrastructure, management and OS used; this is why single CTs seem more suitable for one-to-one comparison than whole container ports [Cullinane *et al.* 2005, Wang *et al.* 2002].

Several stages were required for the construction of the sample. In a first stage, the sample comprised all the CTs of Europe's leading container ports ranked in the top 30 in 2011. In a second stage, with the aim of focusing the analysis only on terminals located in the two main areas for container activity in Europe, i.e. Mediterranean and North West Area, Russian terminals have been excluded from the sample. Finally, traffic requirements have been introduced to exclude from the sample terminals handling less than 75.000 TEUs and inland terminals. Afterwards, few other terminals have been excluded because of data unavailability. The final sample comprises the 65 terminals listed in Appendix 12.

Data collected for each terminal are divided into *terminal variables* and *boundary variables*. The first concern demand and supply data of each CT, specifically:

- terminal throughput in terms of TEUs per year;
- terminal capacity in terms of maximum number of TEUs that can be handled per year;
- transhipment share, calculated as a percentage of the total traffic volume handled by the terminal;
- total yard area (sqm);
- berths length (m);
- number and typology of handling equipment; this data has been essential to identify the OS into use.

The information collected is mainly based on a combination of data deriving from official websites of ports/terminals and secondary sources such as Containerisation International Yearbook (issue 2011) and Dynamar reports (issues 2011-2012). Considering that the most recent complete data on terminal throughput was 2011, this latter has been used as the basis for the study. Afterwards, several CTs taking part in the sample have been approached directly in order to validate the information collected and to overcome the problems related to missing and inconsistent data.

Boundary variables concern:

- labour regime existing in the terminal area;
- port land cost;
- type of terminal operator;
- logistics performance index.

Two variables are here used to describe the labour regime existing in the area: labour cost and rigidity of labour regulation. Given the lack of available and reliable direct data concerning labour cost applied in container ports, a proxy variable is used in this study; it is represented by the average hourly cost of labour on a country basis. This proxy is easy to find on annual European reports and statistics [Eurostat, 2011], whereas an index representing the rigidity of labour regulation on a country basis is derived from *The Global Competitiveness Report 2012-2013* [Schwab 2012]. This index ranges from 1 to 8; lower values indicate strict labour regulation, higher values indicate more permissive regulation.

With regard to the port land cost, there is a lack of homogeneous databases on Industrial land prices for European countries and even in Eurostat surveys only some countries are analysed. To overcome the difficulties in obtaining data, we use the logistics prime rent (€ per sqm p.a.) as a proxy for port land price, as determined in the studies of Jones Lang Lasalle [2012]. For each CT analysed, port land values are referred to the city in which the terminal is located or, when information on the specific city is not available, values of the nearest city are used in replacement.

The typology of the terminal operator may heavily affect the choice of a specific OS. Nowadays, few port authorities directly operate their own terminals while an increasing number of them are acting as landlord ports, meaning that terminals are given in concession to other operators [Talley 2009, Van Hooydonk 2013]. In particular, when dealers are Global Terminal Operators (GTO), corporate policies and capital availability may have a significant weight in the choice of the terminal layout, since objectives and incentives may differ among operators depending on their business strategies [Notteboom and Rodrigue 2012]. In this application we distinguish among terminals run by GTOs, National Operators and Joint Ventures.

The logistics performance index reflects the perceptions of the efficiency of logistics processes on a country basis. The index ranges from 1 to 5, higher scores represent better performances. The index is taken from a survey conducted by the World Bank [2010].

The variables collected for the study are summarised in Table 7.2. The second column shows the coding used for each variable.

Table 7.2 - Application variables.

Variable name	**Variable code**
Terminal Throughput	THRU
Terminal Annual Capacity	CAPC
Transhipment share	TRAN
Total Yard Area	AREA
Berths Length	BERL
Labour Cost	LABC
Labour Regulation	LABR
Port Land Cost	POLC
Terminal Operator Type	TERT

Source: own elaboration.

7.3.2 Variability and other descriptive statistics

The great majority of the CTs of the sample are of smaller size (less than 1 million TEUs), about one third are classifiable as medium-to-large size (ranging from 1 million to 3 million TEUs) and only one CT handles more than 3 million TEUs per annum (see Figure 7.1). With regard to the OS used, the SC system is undoubtedly the most common, exceeding 40 per cent of the sample, followed by the RTG system with a 35 per cent presence, all the other systems do not reach the 10 per cent. For what concerns the terminal management, 60 per cent of the terminals of the sample are run by a GTO, 25 per cent by a National operator and the remaining 15 per cent by a Joint Venture. The average labour cost is 25 €/h but significant differences occur among terminals: the two threshold values are represented by Turkish terminals with an hourly labour cost of 3 € and Swedish terminals with 39 €/h. The scatter plot in Figure 7.2 shows the relationship between terminal throughput and labour cost for each terminal of the sample. Different shapes and colours are used to depict the 65 CTs according to their OS.

More descriptive statistics of all the variables used in this application are reported in Table 7.3 and the correlation matrix is illustrated in Table 7.4.

Table 7.3 - Descriptive statistics of the variables analysed in the study.

Variable	Unit	Obs	Mean	Std.Dev.	Min	Max
LABC	€/h	65	25.48154	10.27489	3	39
LABR	Index	65	3.646154	2.387669	1	8
POLC	€/sqm	63	51.58413	14.14685	27	87
BERL	m	65	1432.077	799.7818	225	4680
AREA	sqm	65	677843.4	541461.1	75000	2853000
CAPC	TEU/year	65	1621908	1190530	200000	6000000
THRU	'000 TEU/year	64	1101.217	953.743	75000	5000000
TRAN	%	65	37.84615	24.81446	4	100

Source: own elaboration.

Table 7.4 - Correlation matrix.

	LABC	LABR	POLC	BERL	AREA	CAPC	THRU	TRAN
LABC	1.000							
LABR	-0.746	1.0000						
POLC	0.117	0.050	1.000					
BERL	0.274	-0.228	0.126	1.000				
AREA	0.310	-0.235	0.218	0.886	1.000			
CAPC	0.196	-0.168	0.177	0.766	0.810	1.000		
THRU	0.095	-0.104	0.220	0.630	0.705	0.929	1.000	
TRAN	-0.272	0.099	-0.383	0.262	0.112	0.266	0.227	1.000

Source: own elaboration.

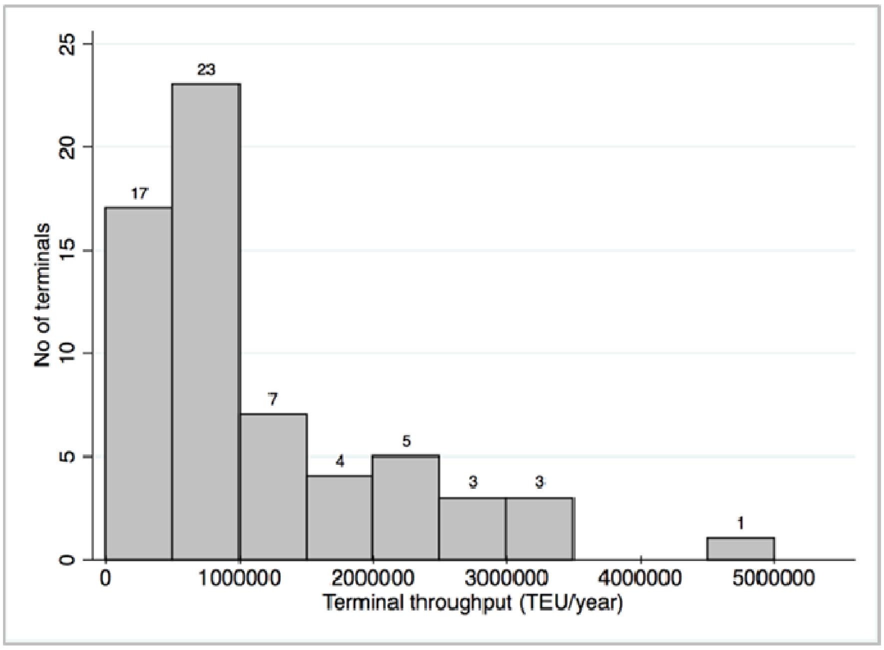

Figure 7.1 - Terminal throughput.
Source: own elaboration.

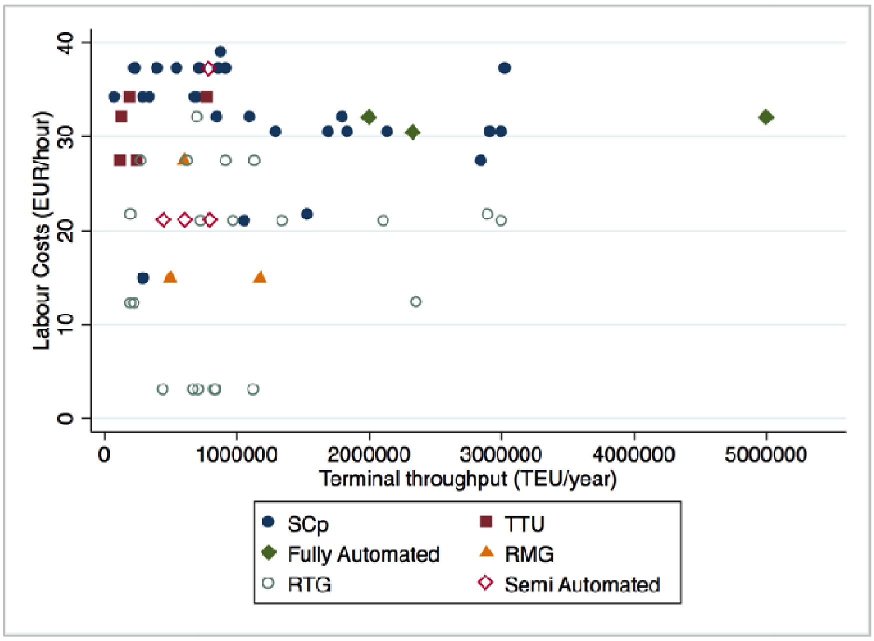

Figure 7.2 – Scatter plot: labour cost, terminal throughput and OS.
Source: own elaboration.

7.3.3 Model description

On the basis of the literature analysis with relation to the major determinants of CT operation systems, the following models have been proposed. All models aim at explaining the choice of one of the six OSs on the basis of the characteristics of the terminal or of the business environment where the terminal operates.

In order to test the model a Multinomial Logit (MNL) specification has been used, where the dependent variable is the Typology of Operating System, hereafter TOS, and the independent variables are the terminal characteristics or the business environment characteristics described in the previous paragraphs.

A multinomial logit model can be seen as the simultaneous estimation of binary logit models where all possible comparisons are taken into account. Assuming that our dependent variable, assume the categories D_1, D_2 and D_3, and we have only one independent variable I either numerical or categorical, the effects of the independent variable on the dependent variable can be examined by estimating three binary logit models:

$$ln\left\{\frac{\Pr(D_1|x)}{\Pr(D_2|x)}\right\} = \beta_{0,D_1|D_2} + \beta_{1,D_1|D_2}I$$
$$ln\left\{\frac{\Pr\,(D_3|x)}{\Pr\,(D_2|x)}\right\} = \beta_{0,D_3|D_2} + \beta_{1,D_3|D_2}I$$
$$ln\left\{\frac{\Pr\,(D_1|x)}{\Pr\,(D_3|x)}\right\} = \beta_{0,D_1|D_3} + \beta_{1,D_1|D_3}I$$

The three logistic regressions include redundant information and the following equality must hold:

$$ln\left\{\frac{\Pr(D_1|x)}{\Pr(D_2|x)}\right\} - ln\left\{\frac{\Pr\,(D_3|x)}{\Pr\,(D_2|x)}\right\} = ln\left\{\frac{\Pr\,(D_1|x)}{\Pr\,(D_3|x)}\right\}$$

that implies that:

$$\beta_{0,D_1|D_2} - \beta_{0,D_3|D_2} = \beta_{0,D_1|D_3}$$
$$\beta_{1,D_1|D_2} - \beta_{1,D_3|D_2} = \beta_{1,D_1|D_3}$$

For a dependent variable with *J* categories, *J-1* logit comparisons need to be estimated.

As previously discussed, the categorical variable TOS counts 6 categorical values, one for each terminal OS observed in the sample. Since SC operated terminals are the majority in our sample, they are used as a baseline operations system.

The relations between variables advanced in the model aim at explaining the choice of categorical value in TOS as a function of the terminal throughput (THRU), a labour cost index (LABC), the percentage of transhipment (TRAN), a labour regulation index (LABR), the global scope of the terminal operator (TERT), the terminal total surface (AREA), the port land cost (POLC), the berth length (BERL). As it is often the case in multinomial models, it is important to obtain the right specification of the model as well as to account for the significance of the selected values. As the goodness of fit (GOF) for multinomial logit models does not provide an index such as R^2, various alternatives have been presented in the literature. In this analysis we will make use of index introduced by McFadden also referred to as 'pseudo' R^2 [McFadden 1974].

The 'pseudo' R^2 has the advantage of being a quite well established measure of GOF for logistic regression and, although other alternatives have been proposed [see for example Cox and Snell 1989; Tjur 2009; Nagelkerk 1991], the 'pseudo' R^2 has the advantage of being rather intuitive. Since logistic regressions are calculated maximising the likelihood function, if we indicate with L_0 the estimated likelihood of a model with no predictors, and with L_M the estimated likelihood of the model being estimated, the McFadden 'pseudo' R^2 is given by the formula:

$$R^2_{McF} = 1 - \frac{\ln(L_M)}{\ln(L_0)}$$

Since typically the analysis of logit models require the investigation of nested models, i.e. models whose specifications are contained in a model with a higher number of independent variables, the logarithm of the likelihood provides a useful indicator in assessing the gains obtained by adding independent variables.

The combinations of variables tested using a logistic regression, are listed in Table 7.5.

Further models were also analysed, but on the basis of the results and the meaningfulness of the relations, the discussion on the model results will be based only on the 18 models listed in the Table 7.5.

Table 7.5 - List of model specifications.

SPECIFICATION	INDEPENDENT VARIABLES					
1	THRU	LABC	TERT	TRAN	POLC	LABR	BERL
2	THRU	LABC	TERT	TRAN	POLC	LABR	
3	THRU	LABC	TERT	TRAN	LABR	LABR	
4	THRU	LABC	TERT	TRAN			
5	THRU	LABC	TERT				
6	THRU	LABC	TRAN				
7	THRU	LABC	POLC				
8	THRU	LABC	LABR				
9	**THRU**	**LABC**	**BERL**				
10	THRU	LABC	AREA				
11	THRU	LABC	TRAN	BERL			
12	THRU	LABC	TRAN	BERL	AREA		
13	THRU	LABC	TRAN	AREA			
14	THRU	LABC					
15	AREA	LABC					
16	LABC	CAPC					
17	CAPC	LABC	BERL				
18	CAPC	TRAN	LABC				

Source: own elaboration.

7.4 Model results: determinants of terminal operating models

Results of the application are discussed in the present paragraph. A summary of the GOF of the 18 models tested above is provided in Table 7.6.

Table 7.6 - Goodness of fit (GOF) for models specified.

Specification	Log Likelihood	pseudo R^2	No of variables	Obs
1	-28.158	0.6756	7	62
2	-38.256	0.5592	6	62
3	-42.617	0.5211	5	64
4	-49.267	0.4464	4	64
5	-51.893	0.4169	3	64
6	-53.639	0.3973	3	64
7	-54.194	0.3756	3	62
8	-52.998	0.4045	3	64
9	**-51.545**	**0.4208**	**3**	**64**
10	-52.051	0.4151	3	64
11	-43.398	0.5123	4	64
12	-38.735	0.5647	5	64
13	-46.568	0.4767	4	64
14	-56.481	0.3653	2	64
15	-58.729	0.3478	2	65
16	-56.036	0.3777	2	65
17	-53.308	0.4080	3	65
18	-52.633	0.4155	3	65

Source: own elaboration.

In addition to the log of the likelihood and the pseudo R^2 an important parameter in the analysis is the significance of the coefficients. From the 18 models tested it turned out that the number of significant coefficients decreases dramatically when the number of explanatory variables is four or above. Therefore those models that had more than 3 variables were excluded. Among the models with three variables the one that explains the choice of terminal OS using throughput, labour costs and berth lengths appears to have the highest GOF (see specification in bold in Tables 7.5 and 7.6).

The model results are specified below. Considering the way logistic regressions outputs are estimated, it might be valuable to look at the significance of the coefficients also using other categories as baseline. Table 7.7 summarises the coefficients for the significant variables at 95%.

Table 7.7 - Coefficients and significance.

TOS	Variable	Coef.	Std. Err.	Z	P>|z|
SCp	*(base outcome)*				
TTU	THRU	-.0021	.002507	-0.82	0.412
	LABC	-.0269	.1180854	-0.23	0.820
	BERL	-.0033	.0023252	-1.43	0.153
	Constant	3.7726	3.686461	1.02	0.306
Fully Automated	THRU	-.0050	.0003060	1.64	0.101
	LABC	.3555	.4364361	0.81	0.415
	BERL	-.0060	.0046321	-1.29	0.197
	Constant	-13.9546	13.97629	-1.00	0.318
RMG	THRU	-.0018	.0001544	-1.18	0.238
	LABC*	-.3055	.1014796	-3.01	0.003
	BERL	.0010	.0008915	1.12	0.264
	Constant*	6.2848	2.758903	2.28	0.023
RTG	THRU	-.00046	.0000006	-0.73	0.468
	LABC*	-.3237	.0820208	-3.95	0.000
	BERL	.0002	.0006842	0.33	0.744
	Constant*	8.4367	2.383842	3.54	0.000
Semi-Automated	THRU	-.0021	.0000014	-1.44	0.151
	LABC*	-.2230	.0916934	-2.43	0.015
	BERL	.00076	.0007897	0.96	0.337
	Constant*	5.2808	2.77747	1.90	0.057

Source: own elaboration.

Throughput

The variable accounting for the different throughput in the terminal (THRU) expressed in 1000 TEU appears to be the best fit among capacity (CAPC) and the surface of the terminal (AREA). The data seem to suggest that the throughput influences the

* Significant at 5%.

choice between automated and semi-automated terminals and RMG. Larger terminals end to favour automation. For the other OSs, the size of the terminal does not seem to be relevant. These conclusions should be looked at with care, considering the limited number of automated and semi-automated terminals in existence today.

A careful interpretation should be given to the coefficients *b*. As commonly in multinomial logistic regressions the *b* coefficients are logarithms of the odd ratios. This implies that if the coefficient is negative, the ratio between the probability of alternative 1 on the probability of alternative 2 is smaller than one. This indicates that the probability of alternative 1 is smaller than the probability of alternative 2. So from the Table 7.8 an increase in the size of the throughput would increase the probability of a fully automated terminal to an RMG operated terminal or a semi-automated terminal.

Table 7.8 - Significant log odd ratio coefficients for the variable 'throughput'.

Odds comparing alternative 1 to alternative 2		**B**	**z**	**P>|z|**
Fully automated	- RMG	0.00685	1.994	0.046
Fully automated	- Semi automated	0.00711	2.095	0.036
RMG	- Fully automated	-0.00685	-1.994	0.046
Semi-automated	- Fully automated	-0.00711	-2.095	0.036

Source: own elaboration.

Labour Costs

Interesting results are observable from the variable LABC. In this case it appears that TTU-operated terminals would be preferred to RMG or RTG terminals in case of an increase of the cost of labour. It should be stressed that the LABC variable provides an indication of the labour costs in the country, and therefore can only be considered as a proxy of the labour costs in a terminal. An increase in the cost of labour would favour TTU-operated terminals to RMG- and RTG-operated terminals. The increase in the cost of labour favours SC-operated terminals to RMG-, RTG- and semi-automated terminals. SC-operated systems require in general less manpower than RTG- or RMG-operated terminals. On average, for every gantry crane, a SC operated system requires 4 or 5 operators, while RMG and RTG systems needs 6 to 8. We would have expected that automated terminals are also favoured as labour costs increase. This is not supported by the data and might be the result of the strong unionisation of the labour force in those countries where labour is expensive. This would in principle prevent the shift towards automated terminals, but the limited amount of observations does not offer conclusive evidence on the issue. Further details are presented in Table 7.9.

Table 7.9 - Significant log odd ratio coefficients for the variable 'Labour Cost'.

Odds comparing alternative 1 to alternative 2		B	z	P>|z|
TTU	- RMG	0.27855	2.062	0.039
TTU	- RTG	0.29679	2.441	0.015
RMG	- TTU	-0.27855	-2.062	0.039
RMG	- SCp	-0.30546	-3.010	0.003
RTG	- TTU	-0.29679	-2.441	0.015
RTG	- SCp	-0.32371	-3.947	0.000
Semi-automated	- SCp	-0.22304	-2.432	0.015
SCp	- RMG	0.30546	3.010	0.003
SCp	- RTG	0.32371	3.947	0.000
SCp	- Semi automated	0.22304	2.432	0.015

Source: own elaboration.

Berth length

The variable berth length does not appear to have significant coefficients at 5%. Its inclusion in the regression model though improves the significance of the other variables.

Other variables

It is expedient to discuss the results of the other models, which were not selected and look at the significance of the other variables that do not appear in the model. On the basis of the 18 models tested Throughput (THRU), capacity (CAPC) and surface (AREA) appear to provide very similar results. They tend to be significant only in explaining the choice for terminals where a certain degree of automation is present. The variables related to the labour force are generally significant and support what is generally accepted in the literature. High labour costs in fact tend to favour SC-operated terminals.

Labour regulation (LABR), on a simple model accounting only for throughput and labour regulation, is significant for the comparisons between RMG and SCs and RTG and SCs; indicating that an increase in labour regulation (a decrease in the LABR variable), favours RMG and RTG systems against SC systems. This seems to confirm the intuition that heavily regulated markets will tend to favour less labour-intensive systems. It should be noted that the variable used for labour cost and labour regulation in our sample show strong heavy negative correlation (Table 7.4). In fact we expect that countries characterized by higher labour costs are also countries more regulated. In our sample an increase in labour cost is negatively correlated to an increase in the labour regulation index: it is necessary to keep in mind that high values of the labour index correspond to more permissive regulation.

The variable port land cost, does not appear to be significant at all. This might be the result of the fact that terminal operators have very special leasing agreements that do not reflect the overall land costs.

The TERT variable distinguishing on the scope of the terminal operator (global, national or joint venture) does not seem to be explanatory to the difference between terminals. This could be explained by the accessibility of various technologies in Europe by all type of operators, independently of whether they are multinationals or not. This might be different in less developed areas of the world. The variable percentage of transhipment (TRAN) is also in general of limited significance. In a simple model with throughput the coefficient of transhipment is only significant in explaining the odds of RMG- or semi-automated-terminals to SC-terminals, implying that an increase in transhipment, would favour RMG and semi-automated terminals against SC-operated terminals.

Finally, a particularly interesting result is obtained when regressing the terminal operation system to the logistics performance index of the country, together with the throughput. This model has a pseudo R^2 of 0.3069, which does not score particularly well with respect to other models. It is interesting though to observe that many of the log odd ratios are significant (see Table 7.10) even at a 1% level. An increase in the logistics performance of the country where the terminal operates appears to favour SC-operated terminals and TTU and semi-automated terminals over RMG. The reasons behind such result are difficult to explain and might be worth further analysis.

Table 7.10 - Significant log odd ratio coefficients for the variable 'logistics performance index' when used as independent variable in association to 'throughput'.

Odds comparing Alternative 1 to alternative 2		**B**	**z**	**P>|z|**
TTU	- RMG	9.00984	2.272	0.023
RMG	- TTU	-9.00984	-2.272	0.023
RMG	- RTG	-3.94819	-1.969	0.049
RMG	- Semi-automated	-7.62631	-2.101	0.036
RMG	- SCp	-11.56585	-3.897	0.000
RTG	- RMG	3.94819	1.969	0.049
RTG	- SCp	-7.61766	-3.516	0.000
Semi-automated	- RMG	7.62631	2.101	0.036
SCp	- RMG	11.56585	3.897	0.000
SCp	- RTG	7.61766	3.516	0.000

Source: own elaboration.

7.5 Conclusion

The present chapter empirically tested the claim that terminal OSs are influenced by the business environment in which the terminal is built. In particular, we wanted to verify the possibility of establishing an empirical relation between the labour regime existing in a terminal, evaluated in terms of labour cost and labour regulation, and the preference for automated models or, more in general, for less labour intensive concepts.

On the basis of a sample of 65 European CTs, it has emerged that some of the determinants identified in the literature, such as labour costs or size of the terminal, have a great influence on the terminal structure. In particular, the increase in the cost of labour favours SC-operated terminals to RMG, RTG and semi-automated terminals. In fact, SC-operated systems are less labour-intensive than RTG or RMG terminals. We would have expected that automated terminals were also favoured as labour costs increase. This was not supported by the data and might be the result of the strong unionisation of the labour force in those countries where labour is expensive. This would in principle prevent the shift towards automated terminals, but the limited amount of observations does not offer conclusive evidence on the issue. With regard to the influence of labour regulations (LABR) on the OS choice, the data collected does not strongly support this theory. The LABR variable was significant only for the comparison of RMG with SC systems and of RTG with SC, on a simple model accounting for throughput and labour regulation; this indicates that a stricter labour regulation favours SC systems (less labour-intensive) against RMG and RTG systems. This seems to confirm the intuition that heavily regulated markets will tend to favour less labour intensive systems.

The characteristics of the terminal flows are also of relevance. In addition to the size of the volumes handled, the analysis has indicated that the percentage of transhipment is a relevant indicator favouring again automated and larger terminals. This supports the typical distinction between gateway terminals and transhipment terminals. This consideration also seems to emerge from the analysis of the logistics infrastructure through a logistics performance index. Higher degrees of logistics performance seem to be associated with SC-operated terminals. These CTs are those dealing with either smaller traffic, or gateway traffic, therefore requiring a higher degree of logistics competences inland.

The application described is among the first attempt to empirically analyse the strategic determinants of the CT operation concepts employed in European CTs. Despite research might suffer from the limited availability of data concerning some variables considered, the analysis performed is relevant for the container area as it contributes to the understanding of the rationale behind the choice of OSs for CTs, choices that in the end impact the attractiveness of the terminals for port users.

The approach proposed to investigate the strategic determinants behind the choice of the CT operating layout is quite novel and, as far as we know, represents the first attempt of this type in the container area. As every new exploratory attempt, further investigation is required to enhance the understanding of the phenomenon in question. Moreover, since MNL models do not consider correlation among the utilities of the various alternatives analysed, the use of alternative models, such as Nested or Mixed Logit, that allow correlation between common groups of alternatives [Daly and Zachary 1978, Koppelman and Sethy 2000], could represent an interesting input to investigate how the proposed analysis would change if correlation within the two main sub-groups of alternatives (manned and automated) was considered.

CHAPTER 8

Conclusions

8.1 Introduction

This chapter provides a summary of the main findings and contributions presented in the thesis. Here we also leave room for improvements in our studies and we discuss some of the different directions that can be taken starting with our findings.

The main purpose of this thesis was to investigate current practices and issues concerning the management of dockworkers in the container terminal (CT) area, in order to propose the analytical methods and policies for its improvement. In the pursuit of this general objective, the research problem has been divided into secondary specific objectives that have been developed in the various chapters of the thesis.

After the introduction chapter, in Chapter 2, we introduced the features and issues of the HR management problem in CTs and we provided a review of the existing literature dealing with the problem addressed. In Chapter 3, we presented a new optimisation model for the daily allocation of dockworkers to shifts, tasks and activities, in which operating and regulatory requirements are taken into account. The ability of the model in finding optimal solutions for realistic problems was demonstrated solving numerical test-instances derived from typical working days at CICT. In Chapter 4, the various cost factors related to longer than expected port handling times were analysed. Moreover, a descriptive cost scheme was presented to illustrate the relationship between manpower shortages occurring in the day and the costs related to the extra-time spent by the vessel in port to complete handling operations. In Chapter 5, the effects of the planning horizon length on the operational management of HR were investigated and an optimisation model encompassing a two-day horizon was used in a rolling horizon fashion to solve realistic-sized instances. Here-and-now decisions deriving from using the two-day horizon were compared to those taken using the daily horizon, by means of the cost scheme illustrated in Chapter 4. Chapter 6 investigated the effects of a greater labour flexibility in CT operations in terms of a more efficient use of the available resources and a reduction in operating costs. Alternative scenarios of labour flexibility were proposed and tested. In Chapter 7, multinomial logit models were formulated to investigate the strategic determinants that lead to the choice of the operating system, and to examine the possibility to establish an empirical relation between the labour regime existing in a CT and the tendency to port automation that is emerging in recent years. The application has provided interesting insights on what strategically motivates the choice of terminal operating systems.

8.2 Research contributions and policy implications

This paragraph summarises the main outcomes and practical implications of the thesis. It is organised into five main sections corresponding to the five specific objectives posed in the introductory chapter.

8.2.1 An optimisation model for the daily allocation of dock workers

In CT activities, the daily planning of workforce deserves special attention because it determines the final system cost incurred by workforce management and it affects the ability of the CT in providing efficient and reliable services. Existing literature shows little attention to workforce management problems in the specific context of maritime CTs. Moreover, the few existing studies assume to have sufficient operators for the workload and do not compute workforce shortage, which is one of the most risky situations in CT activities, because it may result in costly vessel delays and in high penalties charged by shipping companies to CTs. An optimal workforce management is particularly important in the context of transhipment, in which manpower undermanning in the service of mother vessels may result in significant and expensive delays for shipping liners.

In this research we have presented an Integer Linear Programming Model integrating personnel undermanning with the allocation of dockworkers to shifts, tasks and activities, while taking into account different operating and regulatory requirements for internal workers, external workers and manpower shortages. The model determines the optimal allocation of the available workers and it returns shortages in shifts, tasks, and activities, in order to contact overtime workers in time and serve vessels as scheduled. Moreover, a new cost formulation encouraging the assignment of more productive workers to the activities with the highest priorities is introduced to obtain high-quality solutions. To evaluate the ability of the model in solving real-world instances, numerical tests have been carried out on data provided by two important Mediterranean transhipment CTs. For all tested instances, the model has been solved exactly within a very short time using a commercial and a freeware solver. The application performed has shown that existing solvers can be successfully adopted in CT management because they can determine optimal decisions in realistic size instances within the time limits imposed by planning operations. The model can represent a useful support for terminal planners dealing with the daily allocation of manpower.

8.2.2 A cost scheme for delays in port operations

A complete evaluation of the costs related to a lengthening of handling times in port is rather complicated. Terminal operators are traditionally reticent in spreading sensitive information about their business and many of the cost parameters involved are difficult to estimate in monetary terms. In any case, for a better understanding of the extent of the issue in question, in this research we have provided an estimation of three important cost items related to longer port operations times from the vessel operator perspective:

- costs borne by vessels during the extra-time needed to complete handling operations;
- logistics costs related to delays in cargo delivery;
- increased fuel costs in the attempt to catch up part of the delay in reaching the next port of call.

We have developed a cost scheme illustrating the relationship between manpower shortages occurring in the planned day, the extra-time needed to complete operations on vessels and the resulting costs. Since the effects of manpower shortages vary depending on the operating system used, we have analysed the impact of shortages in the two most common CT operating systems, i.e. the direct transfer system based on SCs and the indirect transfer system based on RTGs and TTUs. The effects of manpower shortages appeared to be more pronounced in the RTG system. Besides, using published data we have estimated logistics costs and increased fuel cost related to several port delays, making some assumptions on vessel capacity, amount of containers carried, length of the route and average value of the goods.

8.2.3 The planning horizon length

The length of the planning horizon is an important issue in problem planning, and the existing literature confirms that the results of management problems can be affected by the changes in the length of the planning horizon. Since a longer-than-one-day planning horizon may exploit the visibility of more data, we have investigated the effects of a planning horizon longer than a standard daily one on manpower assignment decisions. To limit the planning horizon to an interval in which problem data are enough accurate, a two-day horizon has been adopted in this research. In fact, due to the ETAs sent by vessels, point forecasts on terminal activities can be considered reasonably reliable within 72 hours from the planning moment. The two-day planning horizon has been included in our optimisation model and used in a rolling horizon fashion so as to compare here-and-now decisions deriving from a one-day and a two-day horizon.

By means of numerical applications derived from real-world CTs, the thesis has illustrated how operators' shortages in a day can be reduced in the model solutions if a two-day planning horizon is used instead of a standard daily one. Furthermore, using the previously mentioned cost scheme, we have compared the practical impact of personnel undermanning that occurs using the one-day horizon with the one that occurs using the two day planning horizon. The lower the workforce shortage, the lower the costs generated by operation delays, the more efficient and competitive is the terminal in the shipping industry. Given its generality and adaptability, the optimisation model and the associate procedure of the extended planning horizon can be applied to several CTs and, hopefully they will support planners in managing HRs more efficiently.

8.2.4 Labour flexibility in the management of dock workers

In manned CTs, labour regime has a fundamental role in determining both day-to-day levels of efficiency and the long-term dynamics of competitiveness. In particular, flexibility in managing workforce is essential in systems characterized by uncertain and fluctuating demand, as the CTs are. However, port labour regimes vary considerably among CTs and, in some CTs, strict work regulations and insufficient labour flexibility prevent an optimal use of the resources available, with a negative impact on competitiveness with respect to other competitors operating under more permissive labour regulations. In this research we have investigated how flexibility improvements can be achieved through slight changes in current labour regulation. We have focused on the specific case of Italian CTs and we have analysed their labour regulations and arrangements. A scenario corresponding to the actual labour regime in Italian ports has been compared to five alternative scenarios, which are constructed by increasing the share of daily working flexibility and introducing a new type of labour flexibility, called *mini-flexibility*. The simulation of the assignments resulting from each scenario has been performed using our optimisation model, whereas economic effects of the assignments are evaluated through the cost scheme described in Chapter 4. The results of this experimentation support the idea that an increased labour flexibility among internal workers can produce a better use of the resources and a reduction in operating costs. In fact, lower manpower shortages and shorter service times occur when a greater labour flexibility is adopted. The findings confirm the importance of labour flexibility in port activities and can be of support for the development of targetted interventions aimed at reducing the gap of competitiveness of European terminals with respect to their nearby competitors located in the southern Mediterranean.

8.2.5 Labour regime and operating system choice

The last part of the research aimed at empirically testing the claim that CT operation systems are influenced by the business environment where the CT is built. In particular, we wanted to investigate, from an empirical perspective, whether the new tendency to CT automation can be considered a consequence of restrictive port labour regimes.

The decision of what system to use is a strategic decision that is based on various and diverse factors. So far this issue has been investigated almost exclusively from a technical point of view, while limited research has been performed in the area of the strategic determinants that lead to the choice of the operating system. To our knowledge, the application proposed in this thesis is the first contribution to the field of studies that empirically investigate what strategically motivates a CT in the choice of the operating system. Despite its exploratory nature, the study has offered an interesting insight on the determinants behind this choice.

Through the use of regression techniques and a sample comprising 65 European CTs, whose major determinants of the operation concepts have been quantified, it has emerged that some of the determinants identified in the existing literature, such as labour costs or terminal size, have a clear influence on the terminal operating layout. However, it appears that the effects of other variables, such as the influence of labour regulation or the share of transhipment traffic, have a weaker support in data. In particular, results of the application have confirmed the claim that operating models that are less labour intensive are more attractive to CTs characterized by high labour costs. Conversely, it has not been possible to establish a sharp relation between restrictive port labour regulation and the tendency to automation; this is probably due to the limited number of automated and semi-automated terminals existing today. Notwithstanding this limitation, these findings enhance the understanding of the reasons behind the choice of OSs and they will hopefully serve as a base for future research in this area.

8.3 Limitations of the research and improvement rooms

At least three limitations characterize the findings presented in this research.

First, the research has stated the manpower planning problem considering the operating and regulatory setting of Italian CTs. Even considering that the general features of the problem are common to all similar port structures, in particular to those mainly devoted to transhipment, and that the generality of the model that we propose allows to adapt it to several operating configurations by updating its parameters to the specific business need, the extent to which our findings can be generalised certainly requires further investigation.

Second, further limitations of the research concern the difficulties to obtain certain information, mainly because of their sensitive nature and the reluctance of the operators in spreading such data; typically such information concerns cost factors or contractual clauses with shipping liners. Cost indications have been used in replacement.

Finally, in Chapter 7 the research suffers from the quality of data concerning some variables considered. Since we were unable to obtain precise information on port land cost and port labour cost because of their sensitive nature, proxy variables have been used in replacement. Furthermore, other data were not available at the terminal level but only at the port level (for example the transhipment share). The availability of higher quality data would have allowed us to perform a more detailed analysis.

8.4 Directions for future research

Research is still in progress to exploit additional characteristics of the problem and to extend the approach to different operating and regulatory settings. Moreover, the continuing relationship with terminal operators is still retaining our attention to develop user-friendly tools to support their complex activity of planning.

Further indications of the topics that in our opinion are most likely to offer valuable opportunities for future analysis are illustrated below.

Our optimisation model is supposed to operate in a deterministic environment in which complete information around the problem is available. Since demand data is supposed to be reasonably reliable in our planning horizon, the uncertainty of planning activities is gradually faced using the two-day horizon model in a rolling horizon fashion and correcting recourse decisions day-by-day, when data application becomes more precise. This research could even take a different direction, for instance, by developing methods to address the HRA problem in CTs under uncertainty. The extension of the planning horizon length leads to explicitly consider the uncertain nature of some parameters of the problem, such as work demand and operating conditions. It is worth noting that, if on the one hand, a further extension of the planning horizon would allow to introduce in the model additional contingent constraints that today are only verified by means of ex-post evaluations (e.g. maximum number of working shifts per week for operator, maximum night shifts per month for operator, etc.), on the other hand, it would lead to a greater uncertainty of the data involved, making traditional deterministic methods highly inefficient in providing good solutions, especially when the future differs significantly from its forecast. In this case, a diverse approach based on stochastic models could be more suitable and might constitute an interesting topic for future research.

With our descriptive cost scheme we have analysed, from the vessel perspective, the costs that are likely to result in case of delays in port operations due to labour inefficiencies. Another interesting area of research could be the evaluation of the economic effects of port operation delays from the terminal operator perspective. The analysis of the impact of port delays on the two main players involved, i.e. the vessel and the terminal operator, would lead to investigate the wider issue of the impact of the disruptions occurring at the port level on the whole supply chain. New research questions arise: what is the role played by the terminal in the supply chain? To what extent the efficiency of the terminal can affect the reliability of the supply chain?

Another input for further research derives from the opportunity to solve integrated problems in managing CT activities. Despite the fact that the various planning activities of a CT are strongly interrelated and that they often share the same resources, they have been mainly treated through separate and independent decision making processes (e.g. forecasting of vessels' arrivals, human resource management, space allocation, equipment scheduling, etc.). Looking at our specific problem, dockworkers perform their operations by means of mechanical equipment. The development of a unified framework for integrating the manpower management with the equipment scheduling problem may represent an interesting challenge for the future; it will allow to integrate two problems that have been faced so far as independent decision making processes.

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APPENDICES

APPENDIX 1 – PROBLEM INSTANCE: *Daily Allocation*

Long-term assignment (x = fixed shift)

Operator ID	Shift - Day 1		
	1	2	3
1	-	x	-
2	x	-	-
3	x	-	-
4	-	-	x
5	-	x	-
6	-	-	x
7	x	-	-
8	x	-	-
9	-	x	-
10	-	x	-
11	-	-	x
12	-	-	x
13	x	-	-
14	-	x	-
15	-	-	x
16	-	x	-
17	x	-	-
18	x	-	-
19	-	x	-
20	x	-	-
21	-	x	-
22	x	-	-
23	x	-	-
24	-	-	x
25	-	x	-
26	-	-	x
27	x	-	-
28	x	-	-
29	-	x	-
30	-	x	-
31	-	-	x
32	-	-	x
33	-	x	-
34	-	x	-
35	-	-	x
36	-	x	-
37	x	-	-
38	x	-	-
39	-	-	x
40	-	x	-
41	-	-	x
42	x	-	-
43	x	-	-
44	-	x	-
45	-	x	-
46	-	-	x
47	-	-	x
48	x	-	-
49	-	x	-
50	-	-	x
51	-	x	-
52	x	-	-
53	x	-	-
54	-	x	-
55	x	-	-
56	-	x	-
57	x	-	-
58	x	-	-
59	-	-	x
60	-	x	-
61	-	-	x
62	x	-	-
63	x	-	-
64	-	x	-
65	-	x	-
66	-	-	x
67	-	-	x
68	-	x	-
69	-	x	-
70	-	-	x
71	-	x	-
72	x	-	-
73	x	-	-
74	-	-	x
75	-	x	-
76	-	-	x
77	x	-	-
78	x	-	-
79	-	x	-
80	-	x	-
81	-	-	x
82	-	-	x
83	x	-	-
84	-	x	-
85	-	-	x

Task priorities and main cost of terminal workers.

Worker ID	Task priority qc	Task priority yc	Task priority tt	Cost [€/h]
1	1*	2	3	25
2	1	2	3	25
3	1	2	3	25
4	1	2	3	25
5	1	2	3	25
6	1	2	3	25
7	x	1	2	23
8	x	1	2	23
9	x	1	2	23
10	x	1	2	23
11	x	1	2	23
12	x	1	2	23
13	x	1	2	23
14	x	1	2	23
15	x	x	1	21
16	x	x	1	21
17	x	x	1	21
18	x	x	1	21
19	x	x	1	21
20	x	x	1	21
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	1	2	3	25
25	1	2	3	25
26	1	2	3	25
27	x	1	2	23
28	x	1	2	23
29	x	1	2	23
30	x	1	2	23
31	x	1	2	23
32	x	1	2	23
33	x	1	2	23
34	x	1	2	23
35	x	x	1	21
36	1	2	3	25
37	1	2	3	25
38	1	2	3	25
39	1	2	3	25
40	1	2	3	25
41	1	2	3	25
42	x	1	2	23
43	x	1	2	23
44	x	1	2	23
45	x	1	2	23
46	x	1	2	23
47	x	1	2	23
48	x	x	1	21
49	x	x	1	21
50	x	x	1	21
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	1	2	3	25
55	1	2	3	25
56	1	2	3	25
57	x	1	2	23
58	x	1	2	23
59	x	1	2	23
60	x	1	2	23
61	x	1	2	23
62	x	1	2	23
63	x	1	2	23
64	x	1	2	23
65	x	x	1	21
66	x	x	1	21
67	x	x	1	21
68	x	x	1	21
69	x	x	1	21
70	x	x	1	21
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	1	2	3	25
75	1	2	3	25
76	1	2	3	25
77	x	1	2	23
78	x	1	2	23
79	x	1	2	23
80	x	1	2	23
81	x	1	2	23
82	x	1	2	23
83	x	1	2	23
84	x	1	2	23
85	x	x	1	21
86	1	2	3	25
87	1	2	3	25
88	1	2	3	25
89	1	2	3	25
90	1	2	3	25
91	1	2	3	25
92	x	1	2	23
93	x	1	2	23
94	x	1	2	23
95	x	1	2	23

* List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	2	qc	3
2	1	qc	1
3	1	yc	2
4	3	yc	3
5	2	yc	1
6	3	yc	3
7	1	yc	3
8	1	yc	3
9	2	yc	1
10	2	yc	1
11	3	yc	4
12	3	yc	4
13	1	yc	3
14	2	yc	1
15	3	tt	1
16	2	tt	3
17	1	tt	2
18	1	tt	1
19	2	tt	2
20	1	tt	1
21	2	yc	2
22	1	yc	1
23	1	yc	1
24	3	qc	3
25	2	yc	2
26	3	qc	3
27	1	yc	4
28	1	yc	2
29	2	yc	3
30	2	yc	3
31	3	tt	1
32	3	yc	1
33	2	yc	4
34	2	yc	4
35	3	tt	1
36	2	tt	1
37	1	yc	2
38	1	qc	1
39	3	yc	1
40	2	tt	1
41	3	yc	1
42	1	yc	2
43	1	yc	4
44	2	tt	1
45	2	tt	1
46	3	tt	2
47	3	tt	2
48	1	tt	2
49	2	tt	1
50	3	tt	2
51	2	tt	1
52	1	qc	2
53	1	qc	2
54	2	tt	2
55	1	qc	3
56	2	qc	1
57	1	tt	3
58	1	tt	3
59	3	yc	1
60	2	tt	2
61	3	tt	3
62	1	tt	3
63	1	tt	3
64	2	tt	2
65	2	tt	2
66	3	tt	3
67	3	tt	3
68	2	tt	2
69	2	tt	3
70	3	tt	3
71	2	qc	1
72	1	tt	3
73	1	tt	3
74	3	qc	1
75	2	qc	2
76	3	qc	1
77	1	tt	2
78	1	tt	2
79	2	tt	3
80	2	yc	2
81	3	yc	2
82	3	yc	2
83	1	yc	3
84	2	yc	2
85	3	tt	3
86	1	yc	1
87	1	qc	3
88	3	qc	2
89	3	qc	2
90	1	yc	1
91	2	qc	2
92	3	yc	2
93	3	yc	2
94	3	yc	3
95	3	yc	3

*z = 1,2,3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	1	4
1	tt	4	1
3	tt	1	3
3	tt	2	3
3	tt	4	3
3	tt	3	1

Allocation results: Manpower shortages

j	k	z*	Number of shortages
1	tt	2	2
1	tt	4	2
2	tt	4	3

Cost of manpower shortages:

Shift	Hourly cost of manpower shortages [€/h]		
	qc	yc	tt
1	130	110	90
2	130	110	90
3	130	110	90

* z = 1,2,3: vessel activity; z = 4: housekeeping.

APPENDIX 2 - PROBLEM INSTANCE: *Days_1_2*

Long term assignment (x = fixed shift)

Operator ID*	Shifts - Day 1				Shifts - Day 2			
	1	2	3	4	5	6	7	8
1	-	-	x	-	-	-	-	-
2	-	x	-	-	-	-	-	-
3	-	x	-	-	-	-	-	-
4	-	-	-	x	-	-	-	-
5	-	-	x	-	-	-	-	-
6	x	-	-	-	-	-	-	-
7	-	x	-	-	-	-	-	-
8	-	x	-	-	-	-	-	-
9	-	-	x	-	-	-	-	-
10	-	-	x	-	-	-	-	-
11	-	-	-	x	-	-	-	-
12	-	-	-	x	-	-	-	-
13	x	-	-	-	-	-	-	-
14	x	-	-	-	-	-	-	-
15	-	-	-	x	-	-	-	-
16	-	-	x	-	-	-	-	-
17	x	-	-	-	-	-	-	-
18	-	x	-	-	-	-	-	-
19	-	-	x	-	-	-	-	-
20	-	x	-	-	-	-	-	-
21	-	-	x	-	-	-	-	-
22	-	x	-	-	-	-	-	-
23	-	x	-	-	-	-	-	-
24	-	-	-	x	-	-	-	-
25	-	-	x	-	-	-	-	-
26	x	-	-	-	-	-	-	-
27	-	x	-	-	-	-	-	-
28	-	x	-	-	-	-	-	-
29	-	-	x	-	-	-	-	-
30	-	-	x	-	-	-	-	-
31	-	-	-	x	-	-	-	-
32	-	-	-	x	-	-	-	-
33	x	-	-	-	-	-	-	-
34	x	-	-	-	-	-	-	-
35	-	-	-	x	-	-	-	-

Operator ID	Shifts - Day 1				Shifts - Day 2			
	1	2	3	4	5	6	7	8
36	-	-	-	-	-	-	x	-
37	-	-	-	-	-	-	-	x
38	-	-	-	-	-	x	-	-
39	-	-	-	-	x	-	-	-
40	-	-	-	-	-	-	x	-
41	-	-	-	-	-	x	-	-
42	-	-	-	-	x	-	-	-
43	-	-	-	-	-	-	-	x
44	-	-	-	-	-	-	x	-
45	-	-	-	-	-	x	-	-
46	-	-	-	-	-	x	-	-
47	-	-	-	-	x	-	-	-
48	-	-	-	-	-	-	x	-
49	-	-	-	-	-	-	x	-
50	-	-	-	-	-	x	-	-
51	-	-	-	-	-	-	-	x
52	-	-	-	-	-	-	-	x
53	-	-	-	-	-	-	x	-
54	-	-	-	-	-	x	-	-
55	-	-	-	-	x	-	-	-
56	-	-	-	-	-	-	x	-
57	-	-	-	-	-	-	-	x
58	-	-	-	-	-	x	-	-
59	-	-	-	-	x	-	-	-
60	-	-	-	-	-	-	x	-
61	-	-	-	-	-	x	-	-
62	-	-	-	-	x	-	-	-
63	-	-	-	-	-	-	-	x
64	-	-	-	-	-	-	x	-
65	-	-	-	-	-	x	-	-
66	-	-	-	-	-	x	-	-
67	-	-	-	-	x	-	-	-
68	-	-	-	-	-	-	x	-
69	-	-	-	-	-	-	x	-
70	-	-	-	-	-	x	-	-

* Operators from 1 to 35 can work only in day 1, whereas operators from 36 to 70 can work in day 2 only.

Task priorities and main cost of terminal workers.

Operator ID	Task priority			Cost [€/h]
	qc	yc	tt	
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	1	2	3	25
5	1	2	3	25
6	1	2	3	25
7	x	1	2	23
8	x	1	2	23
9	x	1	2	23
10	x	1	2	23
11	x	1	2	23
12	x	1	2	23
13	x	1	2	23
14	x	1	2	23
15	x	x	1	21
16	x	x	1	21
17	x	x	1	21
18	x	x	1	21
19	x	x	1	21
20	x	x	1	21
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	1	2	3	25
25	1	2	3	25
26	1	2	3	25
27	x	1	2	23
28	x	1	2	23
29	x	1	2	23
30	x	1	2	23
31	x	1	2	23
32	x	1	2	23
33	x	1	2	23
34	x	1	2	23
35	x	x	1	21
36	1	2	3	25
37	1	2	3	25
38	1	2	3	25
39	1	2	3	25
40	1	2	3	25
41	1	2	3	25
42	x	1	2	23
43	x	1	2	23
44	x	1	2	23
45	x	1	2	23
46	x	1	2	23
47	x	1	2	23
48	x	1	2	23
49	x	1	2	23
50	x	x	1	21
51	x	x	1	21
52	x	x	1	21
53	x	x	1	21
54	x	x	1	21
55	x	x	1	21
56	1	2	3	25
57	1	2	3	25
58	1	2	3	25
59	1	2	3	25
60	1	2	3	25
61	1	2	3	25
62	x	1	2	23
63	x	1	2	23
64	x	1	2	23
65	x	1	2	23
66	x	1	2	23
67	x	1	2	23
68	x	1	2	23
69	x	1	2	23
70	x	x	1	21
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	1	2	3	25
75	1	2	3	25
76	1	2	3	25
77	x	1	2	23
78	x	1	2	23
79	x	1	2	23
80	x	1	2	23
81	x	1	2	23
82	x	1	2	23
83	x	x	1	21
84	x	x	1	21
85	x	x	1	21

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	3	yc	2
2	2	qc	1
3	2	qc	1
4	1	qc	1
4	4	tt	3
5	3	yc	1
6	1	qc	2
6	4	qc	3
7	2	yc	2
8	2	yc	2
9	3	yc	4
10	3	yc	1
11	1	yc	1
11	4	yc	3
12	1	yc	1
12	4	yc	3
13	1	yc	2
13	4	yc	3
14	1	yc	2
14	4	yc	3
15	1	tt	1
15	4	tt	4
16	3	tt	2
17	1	tt	2
17	4	tt	3
18	2	tt	2
19	3	tt	2
20	2	tt	2
21	3	yc	2
22	2	qc	2
23	2	qc	2
24	1	qc	1
24	4	tt	3
25	3	yc	1
26	1	qc	2
26	4	qc	3
27	2	yc	2
28	2	yc	2
29	3	yc	1
30	3	yc	2
31	1	yc	1
31	4	tt	3
32	1	yc	1
32	4	tt	3
33	1	yc	2

Operator ID	j	k	z
33	4	yc	4
34	1	yc	2
34	4	yc	4
35	1	tt	1
35	4	tt	4
36	7	yc	2
37	5	qc	3
37	8	qc	3
38	6	qc	2
39	5	tt	3
39	8	qc	2
40	7	yc	2
41	6	qc	2
42	5	tt	3
42	8	tt	2
43	5	yc	3
43	8	yc	2
44	7	yc	3
45	6	yc	3
46	6	yc	3
47	5	tt	3
47	8	yc	2
48	7	yc	3
49	7	yc	3
50	6	tt	3
51	5	tt	3
51	8	tt	3
52	5	tt	4
52	8	tt	3
53	7	tt	3
54	6	tt	3
55	5	tt	4
55	8	tt	2
56	7	qc	2
57	5	qc	3
57	8	qc	2
58	6	qc	3
59	5	yc	3
59	8	qc	3
60	7	qc	2
61	6	qc	3
62	5	tt	3
62	8	yc	2
63	5	yc	3
63	8	yc	3

Operator ID	j	k	z
64	7	yc	3
65	6	yc	3
66	6	yc	3
67	5	tt	3
67	8	yc	2
68	7	yc	4
69	7	yc	4
70	6	tt	3
71	3	qc	1
71	7	qc	3
72	3	qc	1
72	7	qc	3
73	3	qc	2
73	7	yc	2
74	3	qc	2
74	7	yc	2
75	3	yc	2
75	6	yc	2
76	2	yc	1
76	6	yc	2
77	2	yc	1
77	6	yc	2
78	3	yc	4
78	6	yc	2
79	2	yc	4
79	6	yc	4
80	2	yc	4
80	5	yc	3
80	8	yc	3
81	2	yc	1
81	5	yc	4
81	8	yc	3
82	2	yc	1
82	5	yc	4
82	8	yc	3
83	2	tt	1
83	5	tt	4
83	8	tt	3
84	1	tt	1
84	4	tt	3
84	7	tt	2
85	1	tt	1
85	4	tt	4
85	7	tt	3

* z = 1,2,3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

(Cost of external workers: 25 €/h)

j	k	z*	Number of external workers
1	tt	1	2
1	tt	2	5
2	tt	4	3
2	tt	2	4
2	tt	1	5
3	tt	4	3
3	tt	2	4
3	tt	1	6
6	tt	3	3
7	tt	3	4
8	tt	3	1

Allocation results: Manpower shortages

j	k	z*	Number of shortages
6	tt	2	6
6	tt	4	3
6	yc	4	1
7	tt	2	5
7	tt	4	3
8	tt	2	4
8	tt	3	2

Cost of manpower shortages:

Shift	Hourly cost of manpower shortages [€/h]		
	qc	yc	tt
1	130	110	90
2	130	110	90
3	130	110	90
4	130	110	90
5	80	60	40
6	80	60	40
7	80	60	40
8	80	60	40

* z = 1,2,3: vessel activity; z = 4: housekeeping

APPENDIX 3 – PROBLEM INSTANCE: *Day_1*

Long-term assignment (x = fixed shift)

Operator ID	Shifts – Day 1			
	1	2	3	4
1	-	-	x	-
2	-	x	-	-
3	-	x	-	-
4	-	-	-	x
5	-	-	x	-
6	x	-	-	-
7	-	x	-	-
8	-	x	-	-
9	-	-	x	-
10	-	-	x	-
11	-	-	-	x
12	-	-	-	x
13	x	-	-	-
14	x	-	-	-
15	-	-	-	x
16	-	-	x	-
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	x	-	-
21	-	-	x	-
22	-	x	-	-
23	-	x	-	-
24	-	-	-	x
25	-	-	x	-
26	x	-	-	-
27	-	x	-	-
28	-	x	-	-
29	-	-	x	-
30	-	-	x	-
31	-	-	-	x
32	-	-	-	x
33	x	-	-	-
34	x	-	-	-
35	-	-	-	x

Task priorities and main cost of terminal workers.

Operator ID	Task Priority			Cost [€/h]
	qc	yc	tt	
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	1	2	3	25
5	1	2	3	25
6	1	2	3	25
7	x	1	2	23
8	x	1	2	23
9	x	1	2	23
10	x	1	2	23
11	x	1	2	23
12	x	1	2	23
13	x	1	2	23
14	x	1	2	23
15	x	x	1	21
16	x	x	1	21
17	x	x	1	21
18	x	x	1	21
19	x	x	1	21
20	x	x	1	21
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	1	2	3	25
25	1	2	3	25
26	1	2	3	25
27	x	1	2	23
28	x	1	2	23
29	x	1	2	23
30	x	1	2	23
31	x	1	2	23
32	x	1	2	23
33	x	1	2	23
34	x	1	2	23
35	x	x	1	21
36	1	2	3	25
37	1	2	3	25
38	1	2	3	25
39	1	2	3	25
40	1	2	3	25
41	1	2	3	25
42	x	1	2	23
43	x	1	2	23
44	x	1	2	23
45	x	1	2	23
46	x	1	2	23
47	x	1	2	23
48	x	x	1	21
49	x	x	1	21
50	x	x	1	21

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	3	yc	2
2	2	qc	1
3	2	qc	1
4	1	qc	1
4	4	tt	3
5	3	yc	1
6	1	qc	2
7	2	yc	2
8	2	yc	2
9	3	yc	2
10	3	yc	2
11	1	yc	1
11	4	tt	3
12	1	yc	1
12	4	tt	3
13	1	yc	2
13	4	yc	3
14	1	yc	2
14	4	yc	3
15	1	tt	1
15	4	tt	3
16	3	tt	2
17	1	tt	2
17	4	tt	4
18	2	tt	2
19	3	tt	2
20	2	tt	2
21	3	yc	1
22	2	qc	2
23	2	qc	2
24	1	qc	1
24	4	qc	3
25	3	yc	1
26	1	qc	2
26	4	qc	3
27	2	yc	2
28	2	yc	2
29	3	yc	1
30	3	yc	2
31	1	yc	1
31	4	tt	3

Operator ID	j	k	z*
32	1	yc	1
32	4	yc	3
33	1	yc	2
33	4	yc	4
34	1	yc	2
34	4	yc	4
35	1	tt	1
35	4	tt	4
36	3	qc	1
37	3	qc	1
38	3	qc	2
39	3	qc	2
40	2	yc	1
41	2	yc	1
42	2	yc	1
43	2	yc	1
44	2	yc	4
45	3	yc	4
46	3	yc	4
47	2	yc	4
48	1	tt	1
48	4	tt	4
49	1	tt	1
49	4	tt	3
50	1	tt	1
50	4	tt	3

*z = 1,2,3: vessel activity; z = 4: housekeeping

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	2	5
2	tt	2	4
2	tt	4	3
2	tt	1	2
3	tt	1	6

Allocation results: Manpower shortages

j	k	z*	Number of shortages
2	tt	1	4
3	tt	2	4
3	tt	4	3
1	tt	1	1

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	130	110	90
2	130	110	90
3	130	110	90
4	130	110	90

* z = 1,2,3: vessel activity; z = 4: housekeeping.

APPENDIX 4 – PROBLEM INSTANCE: *Days _2_3*

Long-term assignment (x = fixed shift)

Operator ID*	Shifts - Day 2				Shifts - Day 3			
	1	2	3	4	5	6	7	8
1	-	-	x	-	-	-	-	-
2	-	-	-	x	-	-	-	-
3	-	x	-	-	-	-	-	-
4	x	-	-	-	-	-	-	-
5	-	-	x	-	-	-	-	-
6	-	x	-	-	-	-	-	-
7	x	-	-	-	-	-	-	-
8	-	-	-	x	-	-	-	-
9	-	-	x	-	-	-	-	-
10	-	x	-	-	-	-	-	-
11	-	x	-	-	-	-	-	-
12	x	-	-	-	-	-	-	-
13	-	-	x	-	-	-	-	-
14	-	-	x	-	-	-	-	-
15	-	x	-	-	-	-	-	-
16	-	-	-	x	-	-	-	-
17	-	-	-	x	-	-	-	-
18	-	-	x	-	-	-	-	-
19	-	x	-	-	-	-	-	-
20	x	-	-	-	-	-	-	-
21	-	-	x	-	-	-	-	-
22	-	-	-	x	-	-	-	-
23	-	x	-	-	-	-	-	-
24	x	-	-	-	-	-	-	-
25	-	-	x	-	-	-	-	-
26	-	x	-	-	-	-	-	-
27	x	-	-	-	-	-	-	-
28	-	-	-	x	-	-	-	-
29	-	-	x	-	-	-	-	-
30	-	x	-	-	-	-	-	-
31	-	x	-	-	-	-	-	-
32	x	-	-	-	-	-	-	-
33	-	-	x	-	-	-	-	-
34	-	-	x	-	-	-	-	-
35	-	x	-	-	-	-	-	-

Operator ID	Shifts - Day 2				Shifts - Day 3			
	1	2	3	4	5	6	7	8
36	-	-	-	-	x	-	-	-
37	-	-	-	-	-	x	-	-
38	-	-	-	-	-	-	x	-
39	-	-	-	-	-	-	-	x
40	-	-	-	-	-	-	x	-
41	-	-	-	-	-	x	-	-
42	-	-	-	-	x	-	-	-
43	-	-	-	-	-	x	-	-
44	-	-	-	-	-	-	x	-
45	-	-	-	-	-	-	-	x
46	-	-	-	-	-	-	x	-
47	-	-	-	-	-	x	-	-
48	-	-	-	-	x	-	-	-
49	-	-	-	-	-	x	-	-
50	-	-	-	-	-	-	x	-
51	-	-	-	-	-	-	-	x
52	-	-	-	-	-	-	x	-
53	-	-	-	-	-	x	-	-
54	-	-	-	-	x	-	-	-
55	-	-	-	-	-	x	-	-
56	-	-	-	-	-	-	x	-
57	-	-	-	-	-	-	-	x
58	-	-	-	-	-	-	x	-
59	-	-	-	-	-	x	-	-
60	-	-	-	-	x	-	-	-
61	-	-	-	-	-	x	-	-
62	-	-	-	-	-	-	x	-
63	-	-	-	-	-	-	-	x
64	-	-	-	-	-	-	x	-
65	-	-	-	-	-	x	-	-
66	-	-	-	-	x	-	-	-
67	-	-	-	-	-	x	-	-
68	-	-	-	-	-	-	x	-
69	-	-	-	-	-	-	-	x
70	-	-	-	-	-	-	x	-

* Operators from 1 to 35 can work only in day 2, whereas operators from 36 to 70 can work in day 3 only.

Additional constraints:[*]

- x[71,1,k,z]=0;
- x[72,1,k,z]=0;
- x[73,1,k,z]=0;
- x[74,1,k,z]=0;
- x[75,1,k,z]=0;
- x[78,1,k,z]=0;
- x[84,1,k,z]=0;
- x[84,2,k,z]=0;
- x[85,1,k,z]=0;
- x[85,2,k,z]=0.

[*] Additional constraints are added in order to respect the assignment of the previous day.

Priority of tasks and main cost for internal workers

Operator ID	Task priority			Cost [€/h]
	qc	yc	tt	
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	1	2	3	25
5	1	2	3	25
6	1	2	3	25
7	x	1	2	23
8	x	1	2	23
9	x	1	2	23
10	x	1	2	23
11	x	1	2	23
12	x	1	2	23
13	x	1	2	23
14	x	1	2	23
15	x	x	1	21
16	x	x	1	21
17	x	x	1	21
18	x	x	1	21
19	x	x	1	21
20	x	x	1	21
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	1	2	3	25
25	1	2	3	25
26	1	2	3	25
27	x	1	2	23
28	x	1	2	23
29	x	1	2	23
30	x	1	2	23
31	x	1	2	23
32	x	1	2	23
33	x	1	2	23
34	x	1	2	23
35	x	x	1	21
36	1	2	3	25
37	1	2	3	25
38	1	2	3	25
39	1	2	3	25
40	1	2	3	25
41	1	2	3	25
42	x	1	2	23
43	x	1	2	23
44	x	1	2	23
45	x	1	2	23
46	x	1	2	23
47	x	1	2	23
48	x	1	2	23
49	x	1	2	23
50	x	x	1	21
51	x	x	1	21
52	x	x	1	21
53	x	x	1	21
54	x	x	1	21
55	x	x	1	21
56	1	2	3	25
57	1	2	3	25
58	1	2	3	25
59	1	2	3	25
60	1	2	3	25
61	1	2	3	25
62	x	1	2	23
63	x	1	2	23
64	x	1	2	23
65	x	1	2	23
66	x	1	2	23
67	x	1	2	23
68	x	1	2	23
69	x	1	2	23
70	x	x	1	21
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	1	2	3	25
75	1	2	3	25
76	1	2	3	25
77	x	1	2	23
78	x	1	2	23
79	x	1	2	23
80	x	1	2	23
81	x	1	2	23
82	x	1	2	23
83	x	x	1	21
84	x	x	1	21
85	x	x	1	21

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*	Operator ID	j	k	z	Operator ID	j	k	z
1	3	yc	2	**33**	3	yc	1	**67**	6	yc	3
2	1	qc	1	**34**	3	yc	4	**68**	7	yc	3
2	4	qc	3	**35**	2	tt	2	**69**	5	yc	3
3	2	yc	1	**36**	5	tt	3	**69**	8	yc	3
4	1	tt	1	**36**	8	yc	3	**70**	7	tt	3
4	4	qc	2	**37**	6	yc	2	**71**	3	qc	2
5	3	yc	2	**38**	7	yc	3	**71**	7	qc	3
6	2	qc	2	**39**	5	tt	3	**72**	3	qc	2
7	1	tt	1	**39**	8	qc	2	**72**	7	qc	3
7	4	yc	3	**40**	7	qc	2	**73**	2	qc	1
8	1	yc	4	**41**	6	qc	3	**73**	6	yc	3
8	4	yc	3	**42**	5	tt	3	**74**	3	yc	1
9	3	yc	2	**42**	8	yc	3	**74**	6	qc	2
10	2	yc	2	**43**	6	yc	2	**75**	2	qc	2
11	2	yc	2	**44**	7	yc	3	**75**	5	qc	3
12	1	tt	1	**45**	5	yc	3	**75**	8	qc	3
12	4	yc	2	**45**	8	tt	3	**76**	3	yc	1
13	3	yc	2	**46**	7	yc	2	**76**	6	yc	2
14	3	yc	4	**47**	6	yc	2	**77**	2	yc	1
15	2	tt	2	**48**	5	tt	3	**77**	5	yc	3
16	1	tt	4	**48**	8	yc	2	**77**	8	yc	2
16	4	tt	3	**49**	6	yc	3	**78**	2	yc	4
17	1	tt	1	**50**	7	tt	3	**78**	5	yc	4
17	4	tt	3	**51**	5	tt	4	**78**	8	yc	2
18	3	tt	2	**51**	8	tt	3	**79**	1	yc	1
19	2	tt	2	**52**	7	tt	3	**79**	4	yc	3
20	1	tt	4	**53**	6	tt	3	**79**	7	yc	4
20	4	tt	2	**54**	5	tt	4	**80**	1	yc	1
21	3	qc	1	**54**	8	tt	2	**80**	4	yc	3
22	1	qc	1	**55**	6	tt	3	**80**	7	yc	2
22	4	qc	2	**56**	7	yc	2	**81**	2	yc	4
23	2	yc	2	**57**	5	tt	3	**81**	5	yc	4
24	1	yc	1	**57**	8	qc	2	**81**	8	yc	3
24	4	qc	3	**58**	7	qc	2	**82**	2	yc	2
25	3	qc	1	**59**	6	qc	2	**82**	5	tt	3
26	2	qc	1	**60**	5	qc	3	**82**	8	tt	3
27	1	tt	1	**60**	8	qc	3	**83**	1	tt	1
27	4	yc	2	**61**	6	qc	3	**83**	4	tt	2
28	1	yc	4	**62**	7	yc	2	**83**	8	tt	2
28	4	yc	2	**63**	5	yc	3	**84**	4	tt	2
29	3	yc	1	**63**	8	tt	3	**84**	8	tt	2
30	2	yc	1	**64**	7	yc	3	**85**	4	tt	2
31	2	yc	1	**65**	6	yc	3	**85**	7	tt	3
32	1	yc	1	**66**	5	tt	4				
32	4	yc	2	**66**	8	yc	2				

* z = 1,2,3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	4	1
2	tt	1	6
2	tt	2	3
2	tt	4	3
3	tt	1	6
3	tt	2	5
3	tt	4	3
4	tt	3	4
4	tt	2	2
6	tt	3	4
6	tt	4	3

Allocation results: Manpower shortages

j	k	z*	Number of shortages
6	tt	2	6
6	yc	4	2
7	tt	2	6
7	tt	4	3
7	tt	3	2
7	yc	4	1
8	tt	2	3
8	tt	3	2

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	130	110	90
2	130	110	90
3	130	110	90
4	130	110	90
5	80	60	40
6	80	60	40
7	80	60	40
8	80	60	40

* z = 1,2,3: vessel activity; z = 4: housekeeping.

APPENDIX 5 – PROBLEM INSTANCE: *Day_2*

Long-term assignment (x = fixed shift)

Operator ID	Shifts – Day 2			
	1	2	3	4
1	-	-	x	-
2	-	-	-	x
3	-	x	-	-
4	x	-	-	-
5	-	-	x	-
6	-	x	-	-
7	x	-	-	-
8	-	-	-	x
9	-	-	x	-
10	-	x	-	-
11	-	x	-	-
12	x	-	-	-
13	-	-	x	-
14	-	-	x	-
15	-	x	-	-
16	-	-	-	x
17	-	-	-	x
18	-	-	x	-
19	-	x	-	-
20	x	-	-	-
21	-	-	x	-
22	-	-	-	x
23	-	x	-	-
24	x	-	-	-
25	-	-	x	-
26	-	x	-	-
27	x	-	-	-
28	-	-	-	x
29	-	-	x	-
30	-	x	-	-
31	-	x	-	-
32	x	-	-	-
33	-	-	x	-
34	-	-	x	-
35	-	x	-	-

Additional constraints:[*]

- x[36,1,k,z]=0;
- x[37,1,k,z]=0;
- x[38,1,k,z]=0;
- x[39,1,k,z]=0;
- x[40,1,k,z]=0;
- x[41,1,k,z]=0;
- x[49,1,k,z]=0;
- x[49,2,k,z]=0;
- x[50,1,k,z]=0;
- x[50,2,k,z]=0.

[*] These constraints are derived from the assignment of the operators in the previous day.

Task priorities and main cost of terminal workers.

Operator ID	Task priority qc	yc	tt	Cost [€/h]
1	1*	2	3	25
2	1	2	3	25
3	1	2	3	25
4	1	2	3	25
5	1	2	3	25
6	1	2	3	25
7	x	1	2	23
8	x	1	2	23
9	x	1	2	23
10	x	1	2	23
11	x	1	2	23
12	x	1	2	23
13	x	1	2	23
14	x	1	2	23
15	x	x	1	21
16	x	x	1	21
17	x	x	1	21
18	x	x	1	21
19	x	x	1	21
20	x	x	1	21
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	1	2	3	25
25	1	2	3	25
26	1	2	3	25
27	x	1	2	23
28	x	1	2	23
29	x	1	2	23
30	x	1	2	23
31	x	1	2	23
32	x	1	2	23
33	x	1	2	23
34	x	1	2	23
35	x	x	1	21
36	1	2	3	25
37	1	2	3	25
38	1	2	3	25
39	1	2	3	25
40	1	2	3	25
41	1	2	3	25
42	x	1	2	23
43	x	1	2	23
44	x	1	2	23
45	x	1	2	23
46	x	1	2	23
47	x	1	2	23
48	x	x	1	21
49	x	x	1	21
50	x	x	1	21

* List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	3	yc	1
2	1	qc	1
2	4	qc	2
3	2	yc	1
4	1	tt	1
4	4	qc	3
5	3	qc	2
6	2	yc	2
7	1	tt	1
7	4	tt	2
8	1	yc	4
8	4	yc	2
9	3	yc	2
10	2	yc	2
11	2	yc	2
12	1	tt	1
12	4	yc	2
13	3	yc	2
14	3	yc	2
15	2	tt	2
16	1	tt	4
16	4	tt	3
17	1	tt	1
17	4	tt	3
18	3	tt	2
19	2	tt	2
20	1	tt	4
20	4	tt	2
21	3	yc	2
22	1	qc	1
22	4	qc	2
23	2	qc	2
24	1	tt	1
24	4	qc	3
25	3	qc	2
26	2	qc	2
27	1	tt	1
27	4	yc	2
28	1	yc	4
28	4	yc	3
29	3	yc	1
30	2	yc	1

Operator ID	j	k	z
31	2	yc	2
32	1	yc	1
32	4	yc	2
33	3	yc	1
34	3	yc	1
35	2	tt	2
37	2	yc	1
38	2	qc	1
39	2	qc	1
40	3	qc	1
41	3	qc	1
42	3	yc	4
43	3	yc	4
44	1	yc	1
44	4	yc	3
45	1	yc	1
45	4	yc	3
46	1	yc	1
46	4	yc	3
47	2	yc	4
48	1	tt	4
48	4	tt	2
49	4	tt	2
50	4	tt	2

* z = 1,2,3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
2	tt	2	3
2	tt	1	1
3	tt	1	6
3	tt	2	5
4	tt	3	4
4	tt	2	1

Allocation results: Manpower shortages

j	k	z*	Number of shortages
2	tt	1	5
2	tt	4	3
2	yc	4	1
3	tt	4	3

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	130	110	90
2	130	110	90
3	130	110	90
4	130	110	90

* z = 1,2,3: vessel activity; z = 4: housekeeping.

APPENDIX 6 – PROBLEM INSTANCE: *Scenario 0*

Long-term assignment (x = fixed shift)

Operator ID	Shifts			
	1	2	3	4
1	x	-	-	-
2	-	x	-	-
3	-	-	x	-
4	-	-	-	x
5	x	-	-	-
6	-	x	-	-
7	-	-	x	-
8	-	-	-	x
9	x	-	-	-
10	-	x	-	-
11	-	-	x	-
12	-	-	-	x
13	x	-	-	-
14	-	x	-	-
15	-	-	x	-
16	-	-	-	x
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	-	-	x
21	x	-	-	-
22	-	x	-	-
23	-	-	x	-
24	-	-	-	x
25	x	-	-	-
26	-	x	-	-
27	-	-	x	-
28	-	-	-	x
29	x	-	-	-
30	-	x	-	-
31	-	-	x	-
32	-	-	-	x
33	x	-	-	-
34	-	x	-	-
35	-	-	x	-
36	-	-	-	x
37	x	-	-	-
38	-	x	-	-
39	-	-	x	-
40	-	-	-	x
41	x	-	-	-
42	-	x	-	-
43	-	-	x	-
44	-	-	-	x
45	x	-	-	-
46	-	x	-	-
47	-	-	x	-
48	-	-	-	x
49	x	-	-	-
50	-	x	-	-
51	-	-	x	-
52	-	-	-	x
53	x	-	-	-
54	-	x	-	-
55	-	-	x	-
56	-	-	-	x
57	x	-	-	-
58	-	x	-	-
59	-	-	x	-
60	-	-	-	x
61	x	-	-	-
62	-	x	-	-
63	-	-	x	-
64	-	-	-	x
65	x	-	-	-
66	-	x	-	-
67	-	-	x	-
68	-	-	-	x
69	x	-	-	-
70	-	x	-	-
71	-	-	x	-
72	-	-	-	x
73	x	-	-	-
74	-	x	-	-
75	-	-	x	-
76	-	-	-	x
77	x	-	-	-
78	-	x	-	-
79	-	-	x	-
80	-	-	-	x

Task priorities and main cost of terminal workers.

Operator ID	Task priority qc	Task priority yc	Task priority tt	Cost [€/h]
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	x	1	2	22
5	x	1	2	22
6	x	1	2	22
7	x	x	1	20
8	x	x	1	20
9	x	x	1	20
10	x	x	1	20
11	1	2	3	25
12	1	2	3	25
13	1	2	3	25
14	x	1	2	22
15	x	1	2	22
16	x	1	2	22
17	x	x	1	20
18	x	x	1	20
19	x	x	1	20
20	x	x	1	20
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	x	1	2	22
25	x	1	2	22
26	x	1	2	22
27	x	x	1	20
28	x	x	1	20
29	x	x	1	20
30	x	x	1	20
31	1	2	3	25
32	1	2	3	25
33	1	2	3	25
34	x	1	2	22
35	x	1	2	22
36	x	1	2	22
37	x	x	1	20
38	x	x	1	20
39	x	x	1	20
40	x	x	1	20
41	1	2	3	25
42	1	2	3	25
43	1	2	3	25
44	x	1	2	22
45	x	1	2	22
46	x	1	2	22
47	x	x	1	20
48	x	x	1	20
49	x	x	1	20
50	x	x	1	20
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	x	1	2	22
55	x	1	2	22
56	x	1	2	22
57	x	x	1	20
58	x	x	1	20
59	x	x	1	20
60	x	x	1	20
61	1	2	3	25
62	1	2	3	25
63	1	2	3	25
64	x	1	2	22
65	x	1	2	22
66	x	1	2	22
67	x	x	1	20
68	x	x	1	20
69	x	x	1	20
70	x	x	1	20
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	x	1	2	22
75	x	1	2	22
76	x	1	2	22
77	x	x	1	20
78	x	x	1	20
79	x	x	1	20
80	x	x	1	20
81	1	2	3	25
82	x	1	2	22
83	x	x	1	20
84	x	x	1	20
85	1	2	3	25
86	x	1	2	22
87	x	x	1	20
88	x	x	1	20

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	1	qc	1
2	2	qc	1
3	3	tt	3
4	4	yc	2
5	1	yc	2
6	2	yc	1
7	3	tt	3
8	4	tt	2
9	1	tt	2
10	2	tt	2
11	3	tt	3
12	4	qc	3
13	1	yc	1
14	2	yc	1
15	3	tt	1
16	4	yc	2
17	1	tt	1
18	2	tt	2
19	3	tt	3
20	4	tt	2
21	1	yc	1
22	2	qc	1
23	3	tt	3
24	4	yc	3
25	1	yc	2
26	2	yc	1
27	3	tt	3
28	4	tt	2
29	1	tt	2
30	2	tt	2
31	3	tt	3
32	4	qc	2
33	1	yc	1
34	2	yc	2
35	3	yc	1

Operator ID	j	k	z
36	4	yc	3
37	1	tt	2
38	2	tt	2
39	3	tt	3
40	4	tt	3
41	1	yc	1
42	2	qc	2
43	3	tt	1
44	4	yc	3
45	1	yc	2
46	2	yc	2
47	3	tt	1
48	4	tt	3
49	1	tt	2
50	2	tt	1
51	3	yc	1
52	4	qc	3
53	1	qc	1
54	2	yc	2
55	3	yc	1
56	4	yc	3
57	1	tt	2
58	2	tt	1
59	3	tt	1
60	4	tt	3
61	1	qc	2
62	2	qc	2
63	3	qc	1
64	4	yc	3
65	1	yc	2
66	2	yc	2
67	3	tt	1
68	4	tt	3
69	1	tt	2
70	2	tt	2

Operator ID	j	k	z
71	3	qc	1
72	4	qc	2
73	1	qc	2
74	2	yc	1
75	3	yc	1
76	4	yc	2
77	1	tt	1
78	2	tt	2
79	3	tt	1
80	4	tt	3
81	4	qc	3
82	4	yc	3
83	2	tt	1
84	2	tt	1
85	4	qc	2
86	4	yc	2
87	2	tt	1
88	2	tt	1

* z = 1,2,3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

(Cost of external workers: 25 €/h)

j	k	z*	Number of external workers
1	tt	1	2
4	tt	2	6
4	tt	3	4

Allocation results: Manpower shortages

j	k	z*	Number of shortages
1	tt	1	2
2	tt	4	3
2	yc	4	2
4	tt	4	3
4	yc	2	2
4	yc	4	2

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	50	44	40
2	50	44	40
3	50	44	40
4	50	44	40

* z = 1,2, 3: vessel activity; z = 4: housekeeping.

APPENDIX 7 – PROBLEM INSTANCE: *Scenario 1*

Long-term assignment (x = fixed shift)

Operator ID	Shifts			
	1	2	3	4
1	x	-	-	-
2	-	x	-	-
3	-	-	x	-
4	-	-	-	x
5	x	-	-	-
6	-	x	-	-
7	-	-	x	-
8	-	-	-	x
9	x	-	-	-
10	-	x	-	-
11	-	-	x	-
12	-	-	-	x
13	x	-	-	-
14	-	x	-	-
15	-	-	x	-
16	-	-	-	x
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	-	-	x
21	x	-	-	-
22	-	x	-	-
23	-	-	x	-
24	-	-	-	x
25	x	-	-	-
26	-	x	-	-
27	-	-	x	-
28	-	-	-	x
29	x	-	-	-
30	-	x	-	-
31	-	-	x	-
32	-	-	-	x
33	x	-	-	-
34	-	x	-	-
35	-	-	x	-
36	-	-	-	x
37	x	-	-	-
38	-	x	-	-
39	-	-	x	-
40	-	-	-	x

Operator ID	Shifts			
	1	2	3	4
41	x	-	-	-
42	-	x	-	-
43	-	-	x	-
44	-	-	-	x
45	x	-	-	-
46	-	x	-	-
47	-	-	x	-
48	-	-	-	x
49	x	-	-	-
50	-	x	-	-
51	-	-	x	-
52	-	-	-	x
53	x	-	-	-
54	-	x	-	-
55	-	-	x	-
56	-	-	-	x
57	x	-	-	-
58	-	x	-	-
59	-	-	x	-
60	-	-	-	x
61	x	-	-	-
62	-	x	-	-
63	-	-	x	-
64	-	-	-	x
65	x	-	-	-
66	-	x	-	-
67	-	-	x	-
68	-	-	-	x
69	x	-	-	-
70	-	x	-	-
71	-	-	x	-
72	-	-	-	x

Task priorities and main cost of terminal workers.

Operator ID	Task priority			Cost [€/h]
	qc	yc	tt	
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	x	1	2	22
5	x	1	2	22
6	x	1	2	22
7	x	x	1	20
8	x	x	1	20
9	x	x	1	20
10	x	x	1	20
11	1	2	3	25
12	1	2	3	25
13	1	2	3	25
14	x	1	2	22
15	x	1	2	22
16	x	1	2	22
17	x	x	1	20
18	x	x	1	20
19	x	x	1	20
20	x	x	1	20
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	x	1	2	22
25	x	1	2	22
26	x	1	2	22
27	x	x	1	20
28	x	x	1	20
29	x	x	1	20
30	x	x	1	20
31	1	2	3	25
32	1	2	3	25
33	1	2	3	25
34	x	1	2	22
35	x	1	2	22
36	x	1	2	22
37	x	x	1	20
38	x	x	1	20
39	x	x	1	20
40	x	x	1	20
41	1	2	3	25
42	1	2	3	25
43	1	2	3	25
44	x	1	2	22
45	x	1	2	22
46	x	1	2	22
47	x	x	1	20
48	x	x	1	20
49	x	x	1	20
50	x	x	1	20
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	x	1	2	22
55	x	1	2	22
56	x	1	2	22
57	x	x	1	20
58	x	x	1	20
59	x	x	1	20
60	x	x	1	20
61	1	2	3	25
62	1	2	3	25
63	1	2	3	25
64	x	1	2	22
65	x	1	2	22
66	x	1	2	22
67	x	x	1	20
68	x	x	1	20
69	x	x	1	20
70	x	x	1	20
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	x	1	2	22
75	x	1	2	22
76	x	1	2	22
77	x	x	1	20
78	x	x	1	20
79	x	x	1	20
80	x	x	1	20
81	1	2	3	25
82	x	1	2	22
83	x	x	1	20
84	x	x	1	20
85	1	2	3	25
86	x	1	2	22
87	x	x	1	20
88	x	x	1	20

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z[*]
1	1	qc	1
2	2	qc	1
3	3	tt	3
4	4	yc	2
5	1	yc	2
6	2	yc	1
7	3	tt	3
8	4	tt	2
9	1	tt	1
10	2	tt	2
11	3	tt	3
12	4	yc	2
13	1	yc	1
14	2	yc	1
15	3	yc	1
16	4	yc	3
17	1	tt	2
18	2	tt	2
19	3	tt	3
20	4	tt	2
21	1	yc	1
22	2	qc	2
23	3	tt	3
24	4	yc	2
25	1	yc	2
26	2	yc	2
27	3	tt	1
28	4	tt	3
29	1	tt	2
30	2	tt	2
31	3	tt	3
32	4	qc	2
33	1	yc	1
34	2	yc	2
35	3	yc	1

Operator ID	j	k	z
36	4	yc	2
37	1	tt	2
38	2	tt	2
39	3	tt	1
40	4	tt	3
41	1	qc	1
42	2	qc	2
43	3	tt	1
44	4	yc	3
45	1	yc	2
46	2	yc	2
47	3	tt	1
48	4	tt	3
49	1	tt	2
50	2	tt	2
51	3	yc	1
52	4	qc	2
53	1	qc	2
54	2	yc	2
55	3	yc	1
56	4	yc	2
57	1	tt	2
58	2	tt	2
59	3	tt	1
60	4	tt	3
61	1	qc	2
62	2	qc	1
63	3	qc	1
64	4	yc	3
65	1	yc	2
66	2	yc	1
67	3	tt	1
68	4	tt	3
69	1	tt	2
70	2	tt	1

Operator ID	j	k	z
71	3	qc	1
72	4	qc	2
73	4	qc	3
74	4	yc	3
75	4	yc	3
76	4	yc	3
77	4	tt	2
78	4	tt	2
79	4	tt	2
80	4	tt	2
81	4	qc	3
82	4	yc	2
83	2	tt	1
84	2	tt	1
85	4	qc	3
86	2	yc	1
87	2	tt	1
88	2	tt	1

[*] z = 1,2, 3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	1	5
2	tt	1	1
4	tt	2	3
4	tt	4	3

Allocation results: Manpower shortages

j	k	z*	Number of shortages
1	yc	1	1
2	tt	4	3
2	yc	4	2
4	tt	3	4
4	yc	4	2

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	50	44	40
2	50	44	40
3	50	44	40
4	50	44	40

* z = 1,2, 3: vessel activity; z = 4: housekeeping.

APPENDIX 8 – PROBLEM INSTANCE: *Scenario 2*

Long-term assignment (x = fixed shift)

Operator ID	Shifts			
	1	2	3	4
1	x	-	-	-
2	-	x	-	-
3	-	-	x	-
4	-	-	-	x
5	x	-	-	-
6	-	x	-	-
7	-	-	x	-
8	-	-	-	x
9	x	-	-	-
10	-	x	-	-
11	-	-	x	-
12	-	-	-	x
13	x	-	-	-
14	-	x	-	-
15	-	-	x	-
16	-	-	-	x
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	-	-	x
21	x	-	-	-
22	-	x	-	-
23	-	-	x	-
24	-	-	-	x
25	x	-	-	-
26	-	x	-	-
27	-	-	x	-
28	-	-	-	x
29	x	-	-	-
30	-	x	-	-
31	-	-	x	-
32	-	-	-	x
33	x	-	-	-
34	-	x	-	-
35	-	-	x	-
36	-	-	-	x
37	x	-	-	-
38	-	x	-	-
39	-	-	x	-
40	-	-	-	x

Operator ID	Shifts			
	1	2	3	4
41	x	-	-	-
42	-	x	-	-
43	-	-	x	-
44	-	-	-	x
45	x	-	-	-
46	-	x	-	-
47	-	-	x	-
48	-	-	-	x
49	x	-	-	-
50	-	x	-	-
51	-	-	x	-
52	-	-	-	x
53	x	-	-	-
54	-	x	-	-
55	-	-	x	-
56	-	-	-	x
57	x	-	-	-
58	-	x	-	-
59	-	-	x	-
60	-	-	-	x
61	x	-	-	-
62	-	x	-	-
63	-	-	x	-
64	-	-	-	x

Task priorities and main cost of terminal workers.

Operator ID	Task priority			Cost [€/h]
	qc	yc	tt	
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	x	1	2	22
5	x	1	2	22
6	x	1	2	22
7	x	x	1	20
8	x	x	1	20
9	x	x	1	20
10	x	x	1	20
11	1	2	3	25
12	1	2	3	25
13	1	2	3	25
14	x	1	2	22
15	x	1	2	22
16	x	1	2	22
17	x	x	1	20
18	x	x	1	20
19	x	x	1	20
20	x	x	1	20
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	x	1	2	22
25	x	1	2	22
26	x	1	2	22
27	x	x	1	20
28	x	x	1	20
29	x	x	1	20
30	x	x	1	20
31	1	2	3	25
32	1	2	3	25
33	1	2	3	25
34	x	1	2	22
35	x	1	2	22
36	x	1	2	22
37	x	x	1	20
38	x	x	1	20
39	x	x	1	20
40	x	x	1	20
41	1	2	3	25
42	1	2	3	25
43	1	2	3	25
44	x	1	2	22
45	x	1	2	22
46	x	1	2	22
47	x	x	1	20
48	x	x	1	20
49	x	x	1	20
50	x	x	1	20
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	x	1	2	22
55	x	1	2	22
56	x	1	2	22
57	x	x	1	20
58	x	x	1	20
59	x	x	1	20
60	x	x	1	20
61	1	2	3	25
62	1	2	3	25
63	1	2	3	25
64	x	1	2	22
65	x	1	2	22
66	x	1	2	22
67	x	x	1	20
68	x	x	1	20
69	x	x	1	20
70	x	x	1	20
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	x	1	2	22
75	x	1	2	22
76	x	1	2	22
77	x	x	1	20
78	x	x	1	20
79	x	x	1	20
80	x	x	1	20
81	1	2	3	25
82	x	1	2	22
83	x	x	1	20
84	x	x	1	20
85	1	2	3	25
86	x	1	2	22
87	x	x	1	20
88	x	x	1	20

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	1	qc	1
2	2	qc	1
3	3	tt	3
4	4	yc	3
5	1	yc	2
6	2	yc	1
7	3	tt	3
8	4	tt	2
9	1	tt	2
10	2	tt	2
11	3	qc	1
12	4	qc	2
13	1	yc	1
14	2	yc	2
15	3	yc	1
16	4	yc	3
17	1	tt	2
18	2	tt	2
19	3	tt	3
20	4	tt	3
21	1	yc	1
22	2	qc	2
23	3	tt	1
24	4	yc	2
25	1	yc	2
26	2	yc	2
27	3	tt	3
28	4	tt	3
29	1	tt	2
30	2	tt	2
31	3	tt	1
32	4	yc	2
33	1	yc	2
34	2	yc	2
35	3	yc	1

Operator ID	j	k	z
36	4	yc	2
37	1	tt	2
38	2	tt	2
39	3	tt	1
40	4	tt	3
41	1	qc	1
42	2	qc	2
43	3	yc	1
44	4	yc	2
45	1	yc	2
46	2	yc	2
47	3	tt	1
48	4	tt	3
49	1	tt	2
50	2	tt	2
51	3	qc	1
52	4	yc	2
53	1	qc	2
54	2	yc	1
55	3	yc	1
56	4	yc	3
57	1	tt	2
58	2	tt	1
59	3	tt	1
60	4	tt	3
61	1	qc	2
62	2	qc	1
63	3	tt	1
64	4	yc	2
65	4	yc	3
66	4	yc	3
67	4	tt	3
68	2	tt	2
69	4	tt	2
70	4	tt	2

Operator ID	j	k	z
71	4	qc	3
72	4	qc	3
73	4	qc	3
74	4	yc	3
75	1	yc	1
76	1	yc	1
77	4	tt	2
78	4	tt	2
79	4	tt	2
80	4	tt	2
81	4	qc	2
82	2	yc	1
83	1	tt	1
84	2	tt	1
85	4	qc	2
86	2	yc	1
87	2	tt	1
88	2	tt	1

* z = 1,2, 3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	1	5
2	tt	4	3
2	tt	1	2
4	tt	3	2

Allocation results: Manpower shortages

j	k	z*	Number of shortages
2	yc	4	2
4	tt	4	3
4	yc	4	2
4	tt	2	2
4	tt	3	1

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	50	44	40
2	50	44	40
3	50	44	40
4	50	44	40

[*] z = 1,2, 3: vessel activity; z = 4: housekeeping

APPENDIX 9 – PROBLEM INSTANCE: *Scenario 3*

Long-term assignment (x = fixed shift)

Operator ID	Shifts 1	2	3	4
1	x	-	-	-
2	-	x	-	-
3	-	-	x	-
4	-	-	-	x
5	x	-	-	-
6	-	x	-	-
7	-	-	x	-
8	-	-	-	x
9	x	-	-	-
10	-	x	-	-
11	-	-	x	-
12	-	-	-	x
13	x	-	-	-
14	-	x	-	-
15	-	-	x	-
16	-	-	-	x
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	-	-	x
21	x	-	-	-
22	-	x	-	-
23	-	-	x	-
24	-	-	-	x
25	x	-	-	-
26	-	x	-	-
27	-	-	x	-
28	-	-	-	x
29	x	-	-	-
30	-	x	-	-
31	-	-	x	-
32	-	-	-	x
33	x	-	-	-
34	-	x	-	-
35	-	-	x	-
36	-	-	-	x
37	x	-	-	-
38	-	x	-	-
39	-	-	x	-
40	-	-	-	x
41	x	-	-	-
42	-	x	-	-
43	-	-	x	-
44	-	-	-	x
45	x	-	-	-
46	-	x	-	-
47	-	-	x	-
48	-	-	-	x
49	x	-	-	-
50	-	x	-	-
51	-	-	x	-
52	-	-	-	x
53	x	-	-	-
54	-	x	-	-
55	-	-	x	-
56	-	-	-	x
57	x	-	-	-
58	-	x	-	-
59	-	-	x	-
60	-	-	-	x

Task priorities and main cost of terminal workers.

Operator ID	Task priority			Cost [€/h]
	qc	yc	tt	
1	1*	2	3	25
2	1	2	3	25
3	1	2	3	25
4	x	1	2	22
5	x	1	2	22
6	x	1	2	22
7	x	x	1	20
8	x	x	1	20
9	x	x	1	20
10	x	x	1	20
11	1	2	3	25
12	1	2	3	25
13	1	2	3	25
14	x	1	2	22
15	x	1	2	22
16	x	1	2	22
17	x	x	1	20
18	x	x	1	20
19	x	x	1	20
20	x	x	1	20
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	x	1	2	22
25	x	1	2	22
26	x	1	2	22
27	x	x	1	20
28	x	x	1	20
29	x	x	1	20
30	x	x	1	20
31	1	2	3	25
32	1	2	3	25
33	1	2	3	25
34	x	1	2	22
35	x	1	2	22
36	x	1	2	22
37	x	x	1	20
38	x	x	1	20
39	x	x	1	20
40	x	x	1	20
41	1	2	3	25
42	1	2	3	25
43	1	2	3	25
44	x	1	2	22
45	x	1	2	22
46	x	1	2	22
47	x	x	1	20
48	x	x	1	20
49	x	x	1	20
50	x	x	1	20
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	x	1	2	22
55	x	1	2	22
56	x	1	2	22
57	x	x	1	20
58	x	x	1	20
59	x	x	1	20
60	x	x	1	20
61	1	2	3	25
62	1	2	3	25
63	1	2	3	25
64	x	1	2	22
65	x	1	2	22
66	x	1	2	22
67	x	x	1	20
68	x	x	1	20
69	x	x	1	20
70	x	x	1	20
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	x	1	2	22
75	x	1	2	22
76	x	1	2	22
77	x	x	1	20
78	x	x	1	20
79	x	x	1	20
80	x	x	1	20
81	1	2	3	25
82	x	1	2	22
83	x	x	1	20
84	x	x	1	20
85	1	2	3	25
86	x	1	2	22
87	x	x	1	20
88	x	x	1	20

* List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	1	qc	1
2	2	tt	2
3	3	tt	3
4	4	yc	2
5	1	yc	2
6	2	yc	4
7	3	tt	3
8	4	tt	2
9	1	tt	2
10	2	tt	2
11	3	tt	3
12	4	qc	2
13	1	yc	1
14	2	yc	4
15	3	tt	1
16	4	yc	3
17	1	tt	2
18	2	tt	2
19	3	tt	1
20	4	tt	3
21	1	yc	2
22	2	tt	2
23	3	yc	1
24	4	yc	2
25	1	yc	2
26	2	yc	1
27	3	tt	1
28	4	tt	3
29	1	tt	2
30	2	tt	4
31	3	yc	1
32	4	yc	3
33	1	qc	1
34	2	yc	1
35	3	yc	1

Operator ID	j	k	z
36	4	yc	2
37	1	tt	2
38	2	tt	1
39	3	tt	1
40	4	tt	3
41	1	qc	2
42	2	qc	1
43	3	qc	1
44	4	yc	3
45	1	yc	2
46	2	yc	1
47	3	tt	1
48	4	tt	3
49	1	tt	2
50	2	tt	4
51	3	qc	1
52	4	yc	2
53	1	qc	2
54	2	tt	2
55	3	yc	1
56	4	yc	2
57	1	tt	2
58	2	tt	4
59	3	tt	1
60	4	tt	3
61	4	qc	2
62	2	qc	2
63	2	qc	1
64	4	yc	3
65	4	yc	3
66	2	yc	2
67	2	tt	1
68	4	tt	2
69	4	tt	2
70	2	tt	1

Operator ID	j	k	z
71	2	qc	2
72	4	qc	2
73	4	qc	3
74	2	yc	1
75	2	yc	2
76	4	yc	3
77	4	tt	2
78	2	tt	1
79	2	tt	2
80	4	tt	2
81	4	qc	3
82	2	yc	2
83	2	tt	1
84	4	tt	2
85	4	qc	3
86	2	yc	2
87	2	tt	1
88	4	tt	2

* z = 1,2, 3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	1	6
4	tt	3	4
4	tt	2	2

Allocation results: Manpower shortages

j	k	z*	Number of shortages
1	yc	1	3
4	tt	4	3
4	yc	4	2
4	yc	2	1

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	50	44	40
2	50	44	40
3	50	44	40
4	50	44	40

[*] z = 1,2, 3: vessel activity; z = 4: housekeeping.

APPENDIX 10 – PROBLEM INSTANCE: *Scenario 4*

Long-term assignment (x = fixed shift)

Operator ID	Shifts 1	2	3	4
1	x	-	-	-
2	-	x	-	-
3	-	-	x	-
4	-	-	-	x
5	x	-	-	-
6	-	x	-	-
7	-	-	x	-
8	-	-	-	x
9	x	-	-	-
10	-	x	-	-
11	-	-	x	-
12	-	-	-	x
13	x	-	-	-
14	-	x	-	-
15	-	-	x	-
16	-	-	-	x
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	-	-	x
21	x	-	-	-
22	-	x	-	-
23	-	-	x	-
24	-	-	-	x
25	x	-	-	-
26	-	x	-	-
27	-	-	x	-
28	-	-	-	x
29	x	-	-	-
30	-	x	-	-
31	-	-	x	-
32	-	-	-	x
33	x	-	-	-
34	-	x	-	-
35	-	-	x	-
36	-	-	-	x
37	x	-	-	-
38	-	x	-	-
39	-	-	x	-
40	-	-	-	x
41	x	-	-	-
42	-	x	-	-
43	-	-	x	-
44	-	-	-	x
45	x	-	-	-
46	-	x	-	-
47	-	-	x	-
48	-	-	-	x
49	x	-	-	-
50	-	x	-	-
51	-	-	x	-
52	-	-	-	x
53	x	-	-	-
54	-	x	-	-
55	-	-	x	-
56	-	-	-	x
57	x	-	-	-
58	-	x	-	-
59	-	-	x	-
60	-	-	-	x

Task priorities and main cost of terminal workers.

Operator ID	Task priority qc	Task priority yc	Task priority tt	Cost [€/h]
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	x	1	2	22
5	x	1	2	22
6	x	1	2	22
7	x	x	1	20
8	x	x	1	20
9	x	x	1	20
10	x	x	1	20
11	1	2	3	25
12	1	2	3	25
13	1	2	3	25
14	x	1	2	22
15	x	1	2	22
16	x	1	2	22
17	x	x	1	20
18	x	x	1	20
19	x	x	1	20
20	x	x	1	20
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	x	1	2	22
25	x	1	2	22
26	x	1	2	22
27	x	x	1	20
28	x	x	1	20
29	x	x	1	20
30	x	x	1	20
31	1	2	3	25
32	1	2	3	25
33	1	2	3	25
34	x	1	2	22
35	x	1	2	22
36	x	1	2	22
37	x	x	1	20
38	x	x	1	20
39	x	x	1	20
40	x	x	1	20
41	1	2	3	25
42	1	2	3	25
43	1	2	3	25
44	x	1	2	22
45	x	1	2	22
46	x	1	2	22
47	x	x	1	20
48	x	x	1	20
49	x	x	1	20
50	x	x	1	20
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	x	1	2	22
55	x	1	2	22
56	x	1	2	22
57	x	x	1	20
58	x	x	1	20
59	x	x	1	20
60	x	x	1	20
61	1	2	3	25
62	1	2	3	25
63	1	2	3	25
64	x	1	2	22
65	x	1	2	22
66	x	1	2	22
67	x	x	1	20
68	x	x	1	20
69	x	x	1	20
70	x	x	1	20
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	x	1	2	22
75	x	1	2	22
76	x	1	2	22
77	x	x	1	20
78	x	x	1	20
79	x	x	1	20
80	x	x	1	20
81	1	2	3	25
82	x	1	2	22
83	x	x	1	20
84	x	x	1	20
85	1	2	3	25
86	x	1	2	22
87	x	x	1	20
88	x	x	1	20

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z*
1	1	qc	1
2	2	tt	2
3	3	yc	1
4	4	yc	2
5	1	yc	2
6	2	yc	4
7	3	tt	3
8	4	tt	2
9	1	tt	2
10	2	tt	2
11	3	yc	1
12	4	yc	2
13	1	yc	1
14	2	yc	1
15	3	tt	1
16	4	yc	2
17	1	tt	2
18	2	tt	2
19	3	tt	3
20	4	tt	3
21	1	yc	2
22	2	yc	2
23	3	yc	1
24	4	yc	3
25	1	yc	2
26	2	yc	1
27	3	tt	3
28	4	tt	3
29	1	tt	2
30	2	tt	2
31	3	qc	1
32	4	qc	2
33	1	qc	1
34	2	yc	1
35	3	tt	1
36	4	yc	2
37	1	tt	2
38	2	tt	2
39	3	tt	1
40	4	tt	3
41	1	qc	2
42	2	qc	1
43	3	qc	1
44	4	yc	3
45	1	yc	2
46	2	yc	1
47	3	tt	1
48	4	tt	3
49	1	tt	2
50	2	tt	1
51	3	yc	1
52	4	yc	2
53	1	qc	2
54	2	tt	1
55	3	tt	1
56	4	yc	2
57	1	tt	2
58	2	tt	1
59	3	tt	1
60	4	tt	3
61	4	qc	3
62	2	qc	2
63	2	qc	1
64	4	yc	3
65	4	yc	3
66	2	yc	2
67	2	tt	1
68	4	tt	2
69	4	tt	2
70	2	tt	2
71	2	qc	2
72	4	qc	3
73	4	qc	3
74	2	yc	2
75	2	yc	2
76	4	yc	3
77	4	tt	2
78	2	tt	1
79	2	tt	1
80	4	tt	2
81	4	qc	2
82	4	yc	3
83	4	tt	3
84	4	tt	3
85	4	qc	2
86	1	yc	1
87	4	tt	3
88	4	tt	3

* z = 1,2, 3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	1	6
2	tt	4	2
4	tt	2	4

Allocation results: Manpower shortages

j	k	z*	Number of shortages
1	yc	1	2
2	yc	4	1
2	tt	4	1
4	tt	4	3
4	yc	4	2

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	50	44	40
2	50	44	40
3	50	44	40
4	50	44	40

* z = 1,2, 3: vessel activity; z = 4: housekeeping.

APPENDIX 11 – PROBLEM INSTANCE: *Scenario 5*

Long-term assignment (x = fixed shift)

Operator ID	Shifts 1	2	3	4
1	x	-	-	-
2	-	x	-	-
3	-	-	x	-
4	-	-	-	x
5	x	-	-	-
6	-	x	-	-
7	-	-	x	-
8	-	-	-	x
9	x	-	-	-
10	-	x	-	-
11	-	-	x	-
12	-	-	-	x
13	x	-	-	-
14	-	x	-	-
15	-	-	x	-
16	-	-	-	x
17	x	-	-	-
18	-	x	-	-
19	-	-	x	-
20	-	-	-	x
21	x	-	-	-
22	-	x	-	-
23	-	-	x	-
24	-	-	-	x
25	x	-	-	-
26	-	x	-	-
27	-	-	x	-
28	-	-	-	x
29	x	-	-	-
30	-	x	-	-
31	-	-	x	-
32	-	-	-	x
33	x	-	-	-
34	-	x	-	-
35	-	-	x	-
36	-	-	-	x
37	x	-	-	-
38	-	x	-	-
39	-	-	x	-
40	-	-	-	x

Operator ID	Shifts 1	2	3	4
41	x	-	-	-
42	-	x	-	-
43	-	-	x	-
44	-	-	-	x
45	x	-	-	-
46	-	x	-	-
47	-	-	x	-
48	-	-	-	x
49	x	-	-	-
50	-	x	-	-

Task priorities and main cost of terminal workers.

Operator ID	Task priority			Cost [€/h]
	qc	yc	tt	
1	1[*]	2	3	25
2	1	2	3	25
3	1	2	3	25
4	x	1	2	22
5	x	1	2	22
6	x	1	2	22
7	x	x	1	20
8	x	x	1	20
9	x	x	1	20
10	x	x	1	20
11	1	2	3	25
12	1	2	3	25
13	1	2	3	25
14	x	1	2	22
15	x	1	2	22
16	x	1	2	22
17	x	x	1	20
18	x	x	1	20
19	x	x	1	20
20	x	x	1	20
21	1	2	3	25
22	1	2	3	25
23	1	2	3	25
24	x	1	2	22
25	x	1	2	22
26	x	1	2	22
27	x	x	1	20
28	x	x	1	20
29	x	x	1	20
30	x	x	1	20
31	1	2	3	25
32	1	2	3	25
33	1	2	3	25
34	x	1	2	22
35	x	1	2	22
36	x	1	2	22
37	x	x	1	20
38	x	x	1	20
39	x	x	1	20
40	x	x	1	20
41	1	2	3	25
42	1	2	3	25
43	1	2	3	25
44	x	1	2	22
45	x	1	2	22
46	x	1	2	22
47	x	x	1	20
48	x	x	1	20
49	x	x	1	20
50	x	x	1	20
51	1	2	3	25
52	1	2	3	25
53	1	2	3	25
54	x	1	2	22
55	x	1	2	22
56	x	1	2	22
57	x	x	1	20
58	x	x	1	20
59	x	x	1	20
60	x	x	1	20
61	1	2	3	25
62	1	2	3	25
63	1	2	3	25
64	x	1	2	22
65	x	1	2	22
66	x	1	2	22
67	x	x	1	20
68	x	x	1	20
69	x	x	1	20
70	x	x	1	20
71	1	2	3	25
72	1	2	3	25
73	1	2	3	25
74	x	1	2	22
75	x	1	2	22
76	x	1	2	22
77	x	x	1	20
78	x	x	1	20
79	x	x	1	20
80	x	x	1	20
81	1	2	3	25
82	x	1	2	22
83	x	x	1	20
84	x	x	1	20
85	1	2	3	25
86	x	1	2	22
87	x	x	1	20
88	x	x	1	20

[*] List of symbols: 1=main task, 2=secondary task, 3=further task, x=task not allowed.

Allocation results: Internal workers

Operator ID	j	k	z[*]
1	1	qc	1
2	2	qc	1
3	3	qc	1
4	4	yc	3
5	1	yc	2
6	2	yc	4
7	3	tt	1
8	4	tt	3
9	1	tt	2
10	2	tt	2
11	3	qc	1
12	4	yc	3
13	1	yc	2
14	2	yc	4
15	3	tt	1
16	4	yc	2
17	1	tt	2
18	2	tt	4
19	3	tt	1
20	4	tt	3
21	1	qc	1
22	2	tt	2
23	3	yc	1
24	4	yc	2
25	1	yc	2
26	2	yc	1
27	3	tt	1
28	4	tt	3
29	1	tt	2
30	2	tt	4
31	3	yc	1
32	4	yc	2
33	1	qc	2
34	2	yc	1
35	3	yc	1

Operator ID	j	k	z
36	4	yc	2
37	1	tt	2
38	2	tt	1
39	3	tt	1
40	4	tt	3
41	1	qc	2
42	2	tt	2
43	3	yc	1
44	4	yc	2
45	1	yc	2
46	2	tt	2
47	3	tt	1
48	4	tt	3
49	1	tt	2
50	2	tt	1
51	2	qc	2
52	4	qc	2
53	4	qc	2
54	2	yc	2
55	2	yc	1
56	4	yc	3
57	4	tt	2
58	2	tt	2
59	2	tt	1
60	4	tt	2
61	4	qc	3
62	2	qc	2
63	2	yc	1
64	4	yc	3
65	4	yc	3
66	2	yc	2
67	2	tt	1
68	4	tt	2
69	4	tt	2
70	2	tt	2

Operator ID	j	k	z
71	2	qc	1
72	4	qc	3
73	4	qc	3
74	2	yc	2
75	2	yc	2
76	4	yc	3
77	4	tt	2
78	2	tt	1
79	2	tt	1
80	4	tt	2
81	4	yc	2
82	1	yc	1
83	1	tt	2
84	4	tt	3
85	4	qc	2
86	1	yc	1
87	4	tt	3
88	4	tt	3

[*] z = 1, 2, 3: vessel activity; z = 4: housekeeping.

Allocation results: External workers

Cost of external workers: 25 €/h

j	k	z*	Number of external workers
1	tt	1	6
4	tt	2	3
4	tt	4	3

Allocation results: Manpower shortages

j	k	z*	Number of shortages
1	yc	1	2
2	tt	4	1
4	yc	4	2
4	tt	3	1

Cost of manpower shortages:

Shift	Hourly cost of shortage [€/h]		
	qc	yc	tt
1	50	44	40
2	50	44	40
3	50	44	40
4	50	44	40

[*] z = 1,2, 3: vessel activity; z = 4: housekeeping.

APPENDIX 12 – LIST OF THE 65 EU CTs ANALYSED IN CHAPTER 7

	Terminal Name	Port	Country
1	Antwerp Gateway Deurganck Dock Berths	Antwerp	Belgium
2	Churchill Terminal Berth (multipurpose)		
3	Delwaide Dock Berths		
4	Deurganck Terminal		
5	Europe Terminal		
6	MSC Home Terminal		
7	Noordzee Terminal		
8	APM Terminal Zeebrugge	Zeebrugge	
9	CHZ Terminal		
10	Terminal de France	Le Havre	France
11	Terminal de l'Atlantique		
12	Terminal Porte Oceane		
13	Terminal de l'Ocean		
14	Terminal de Normandie MSC		
15	Terminal de Mediterranèe - Fos	Marseille	
16	Mourepiane Med EuropeTerminal		
17	Eurogate Container Terminal CTB	Bremen/Bremerhaven	Germany
18	MSC Gate Container terminal		
19	North Sea Terminal		
20	Container Terminal Altenwerder	Hamburg	
21	Eurogate Container Terminal		
22	Container Terminal Burchardkai		
23	Container Terminal Tollerort		
24	New Ikonean Container Terminal (NICT) - Pier I	Piraeus	Greece
25	Piraeus Container Terminal (PCT) - Pier II		
26	Thessaloniki Container Terminal	Thessaloniki	
27	CICT- Cagliari International Container Terminal	Cagliari	Italy
28	Messina Terminal	Genoa	
29	Southern European Container Hub terminal		
30	Voltri Terminal		
31	MCT - Medcenter Container Terminal	Gioia Tauro	
32	La Spezia Container Terminal LSCT	La Spezia	
33	Terminal del Golfo		
34	Taranto Container Terminal TCT	Taranto	
35	Malta Freeport - Terminal one	Malta	Malta
36	Malta Freeport - Terminal two		
37	APM Terminal Rotterdam	Rotterdam	Netherlands
38	ECT City Terminal		
39	ECT Delta Terminal		
40	ECT Euromax Terminal		
41	Rotterdam Short Sea terminal		
42	Uniport Multipurpose Terminal		
43	United Waalhaven Terminal		
44	Alcantara-Sul Container Terminal	Lisbon	Portugal
45	Santa Apolonia Container Terminal		

46	APM terminal (previously Terminal 2000)	Algeciras	Spain
47	TTIA - Isla Verde CT (opened in 2010)		
48	Terminal Catalunya TERCAT - Principe de Espana	Barcelona	
49	Barcelona Europe South Terminal (new opening 2012)		
50	Terminal Muelle Sur Wharf		
51	Noatum Container Terminal Malaga	Malaga	
52	MSC Terminal Valencia	Valencia	
53	Noatum Container Terminal Valencia		
54	Terminal TCV - Muelle de Levante		
55	Port of Gothenburg AB	Gothenburg	Sweden
56	Landguard Container Terminal	Felixstowe	United Kingdom
57	South Terminal (new opening)		
58	Trinity Container Terminal		
59	Southampton CT	Southampton	
60	Kumport	Ambarli	Turkey
61	Mardas		
62	Marport Main Terminal		
63	Marport West Terminal		
64	Izmir Container Terminal	Izmir	
65	Mersin Container Terminal	Mersin	

Source: own elaboration.

ITALIAN SUMMARY

L'obiettivo principale di questa tesi è fornire una panoramica delle pratiche e delle problematiche concernenti la gestione del lavoro nell'ambito dei Container Terminal (CT) marittimi, al fine di suggerire metodi analitici e strategie politiche per un suo miglioramento.
Il focus della ricerca è riposto nella pianificazione operativa (24/48 h), la quale determina il sistema finale dei costi operativi di un CT e influenza in modo rilevante la capacità del terminale stesso nel raggiungere elevati livelli di produttività e garantire servizi di alta qualità agli operatori navali.

Partendo da una collaborazione con due importanti CT di transhipment operanti nel bacino del Mediterraneo (CICT - Cagliari International Container Terminal e MCT - Gioia Tauro Med-center Container Terminal), la ricerca analizza le caratteristiche e le criticità riguardanti il management delle risorse umane in questi CTs e, più in generale, nei CTs Italiani, al fine di proporre nuove tecniche di ottimizzazione e strategie in grado di supportare i planners portuali nel complesso processo decisionale.

Il management operativo delle risorse umane nei CTs è caratterizzato da elevata complessità a causa delle variabili e dei vincoli coinvolti e della natura incerta della domanda. Questi fattori rendono inefficace in ambito portuale l'applicazione dei tradizionali modelli di *staff scheduling*. Nella maggior parte dei CTs la gestione della manodopera è vincolata da severe norme sul lavoro portuale che impongono che i turni lavorativi degli operatori siano pianificati con diversi mesi di anticipo, quando l'effettiva domanda di lavorazioni è ancora altamente incerta. Il principale rischio che ne consegue a livello operativo è il sottodimensionamento della manodopera disponibile nel giorno che si sta pianificando, con l'insorgere di costose carenze di personale e conseguenti ritardi nel completamento delle operazioni di movimentazione sui vettori navali. La letteratura esistente mostra insufficiente attenzione al problema della gestione del personale nello specifico contesto dei porti container. Inoltre, i pochi modelli esistenti assumono di avere sempre a disposizione un quantitativo di manodopera sufficiente a coprire la domanda di lavorazioni del giorno, trascurando le carenze di personale. Queste ultime rappresentano una delle situazioni più pericolose nell'operato di un terminal portuale, determinando ritardi e costi addizionali non necessari, sia per l'operatore terminalista che per l'operatore navale. Per superare questo gap la tesi propone un modello di Programmazione Lineare Intera per

l'allocazione giornaliera della manodopera portuale, in cui l'individuazione delle carenze di manodopera viene integrata con la procedura di assegnazione dei lavoratori portuali a turni, mansioni e attività, soddisfacendo al contempo i diversi vincoli operativi e normativi presenti. Il modello determina l'allocazione di minimo costo per gli operatori a disposizione nel giorno pianificato e restituisce, minimizzandole, eventuali carenze di personale nei diversi turni per le diverse mansioni e attività. Il modello proposto presenta diversi aspetti di originalità rispetto agli studi disponibili in letteratura [Legato and Monaco 2004, Monaco *et al.* 2009]: la questione fondamentale delle carenze di personale è introdotta nel problema di assegnazione quale variabile decisionale, viene definita una nuova formulazione di costo per i lavoratori portuali sulla base della produttività del lavoro e del livello di priorità delle lavorazioni, e vengono specificati nuovi vincoli. La ricerca solleva per la prima volta la questione fondamentale delle carenze di personale nelle attività di un CT, mostrando, attraverso uno schema di costo, l'impatto pratico del sotto-dimensionamento della forza lavoro sui ritardi nelle operazioni portuali e sui costi ad essi associati, assumendo il caso di compagnie navali che sperimentano *turnaround times* più lunghi del previsto.
L'abilità del modello nel risolvere istanze reali è verificata attraverso numerosi test, sviluppati su istanze numeriche fornite dai due terminali in studio. La fase di test mostra che il modello di ottimizzazione sviluppato può essere efficacemente risolto in tempi brevissimi (qualche secondo), per mezzo di solutori esistenti, restituendo una soluzione ottima per tutte le istanze testate.

Poiché un ampliamento dell'orizzonte temporale può consentire la visibilità di un maggiore quantitativo di dati e informazioni, la tesi cerca di investigare gli effetti di un orizzonte di pianificazione più lungo delle 24 ore, sulle decisioni concernenti il primo giorno pianificato. Al fine di limitare la lunghezza dell'orizzonte temporale ad un intervallo in cui il dato di domanda possa considerarsi sufficientemente accurato, si è deciso di adottare un orizzonte temporale di 48 ore, considerato che, grazie agli ETA periodicamente inviati dalle compagnie di navigazione, i punti previsionali sulle attività del terminale possono essere ritenuti ragionevolmente affidabili entro 72 ore a partire dal momento in cui viene effettuata la pianificazione. Poiché nel rispetto della regolamentazione portuale l'assegnazione ai turni deve necessariamente essere determinata con almeno 24 ore di anticipo, questi punti previsionali possono essere impiegati per gestire le risorse umane nell'intervallo compreso tra le 24 e le 72 ore successive al momento in cui viene effettuata la pianificazione. L'orizzonte di pianificazione bi-giornaliero è quindi introdotto nel modello di ottimizzazione citato in precedenza, il quale è utilizzato secondo la logica del *rolling horizon,* al fine di confrontare le decisioni di tipo *here-and-now* derivanti dall'impiego dell'orizzonte giornaliero e di quello bi-giornaliero. Le decisioni sono assunte dal modello per tutti i periodi (turni) dell'orizzonte di pianificazione ma solamente quelle concernenti il primo giorno sono implementate immediatamente, quelle riguardanti il secondo giorno potranno invece essere modificate in un secondo momento nel caso in cui nuove informazioni dovessero rendersi disponibili. Attraverso applicazioni numeriche derivate dai due CTs in studio, la ricerca dimostra come le carenze di manodopera possano essere ridotte nelle soluzioni del modello, nel caso in cui si scelga di adottare un orizzonte bi-giornaliero in sostituzione di uno giornaliero.

Nei CTs tradizionali, principalmente basati sul lavoro umano, il regime lavorativo ha un ruolo fondamentale nel determinare sia l'efficienza giornaliera sia le dinamiche di competitività di lungo termine tra porti concorrenti. In particolare, in un sistema caratterizzato da elevata incertezza e fluttuabilità della domanda come quello portuale, la flessibilità del lavoro rappresenta una delle principali determinanti delle performances ottenibili. Tuttavia i regimi del lavoro portuale possono variare in modo considerevole tra i diversi CTs, e può accadere che in alcuni di questi la rigidità della regolamentazione e la scarsa flessibilità del lavoro siano tali da impedire un impiego ottimale delle risorse disponibili, con impatti negativi in termini di riduzione del livello di servizio offerto alle compagnie navali, incremento dei costi operativi e conseguente perdita di competitività nei confronti dei terminali concorrenti. In questi casi, anche una gestione ottimale della manodopera, implementata attraverso un efficace strumento analitico, può non essere sufficiente per assicurare al terminale una posizione competitiva, in un mercato caratterizzato da concorrenti operanti sotto apparati normativi più permissivi e con costi del lavoro sensibilmente più bassi. Con riferimento al caso Mediterraneo, la competizione tra i diversi CTs è oggi distorta da una serie di eterogeneità economico-normative che, di fatto, collocano i terminali nazionali, e più in generale europei, in una posizione di forte svantaggio competitivo rispetto ai competitors localizzati nella costa Sud del Mediterraneo. Focalizzando l'attenzione sul caso italiano, la tesi propone diversi scenari alternativi di flessibilità e, attraverso l'impiego di uno schema di costo e del modello di ottimizzazione sviluppato, dimostra come piccole variazioni sulle politiche di flessibilità possano produrre un miglior impiego delle risorse disponibili, riducendo il gap competitivo del terminale. Nonostante il processo decisionale non possa essere, per ovvie ragioni, parte della ricerca, i risultati di quest'ultima possono guidare i decisori politici nel loro processo decisionale, fornendo una profonda conoscenza del problema basata su elementi oggettivi.

Nel tentativo di ottenere una prospettiva più ampia del problema, e comprendere se sia possibile stabilire una relazione empirica tra la nuova tendenza verso l'automazione portuale e la rigidità del regime lavorativo esistente, l'ultima parte dello studio cerca di investigare la tesi secondo cui la scelta del sistema operativo adottato in un CT sia fortemente influenzata dal contesto aziendale in cui il CT si trova ad operare.

La decisione riguardante il sistema operativo da adottare in un CT è strategica e basata su diversi fattori. Il problema è stato finora investigato quasi esclusivamente da un punto di vista tecnico, mentre pochissimo è stato detto per quanto concerne le determinanti strategiche di questa scelta. L'applicazione proposta costituisce probabilmente il primo contributo nell'area degli studi che analizzano, da un punto di vista empirico, cosa strategicamente motiva la scelta del sistema operativo adottato. Dall'analisi effettuata con tecniche di regressione su un data set di 65 CTs europei, emerge che alcuni dei fattori identificati in letteratura, quali il costo del lavoro o le dimensioni del terminale, sembrano effettivamente avere un'influenza rilevante sul layout operativo del terminale stesso. Sembra invece che l'effetto di altre variabili, quali l'influenza delle regolamentazioni sul lavoro portuale o la composizione del traffico servito, sia debolmente supportato dai dati. I risultati dell'applicazione confermano l'ipotesi secondo cui i modelli operativi meno *labour-intensive* siano quelli più attrattivi nei CTs caratterizzati da elevati costi del lavoro. Al contrario non è stato finora possibile stabilire una relazione significativa tra la rigidità del regime del lavoro portuale e la tendenza all'automazione; il motivo va probabilmente ricercato nelle caratteristiche del campione adottato in cui solo 7 CT su 65 presentavano caratteristiche di automazione (ad oggi, nonostante la tendenza sia in aumento, sono ancora pochissimi i CT che presentano caratteristiche di automazione del piazzale).

Le tematiche descritte sono discusse negli otto capitoli della tesi. Il Capitolo 1 introduce la tesi e fornisce una panoramica generale del problema trattato. Il Capitolo 2 discute le caratteristiche e le criticità connesse alla gestione delle risorse umane nei CTs e offre una review della letteratura esistente nel settore, individuandone i principali limiti. Il Capitolo 3 presenta il modello di ottimizzazione per l'allocazione giornaliera dei lavoratori portuali a turni, mansioni e lavorazioni, e ne descrive un'applicazione pratica su istanze numeriche derivate dall'operato di CICT. Il Capitolo 4 analizza i diversi fattori di costo legati a tempi di lavorazione in porto più lunghi del previsto e, attraverso uno schema di costo, illustra la relazione esistente tra le carenze di personale e i costi conseguenti al tempo addizionale che la nave dovrà spendere in porto per poter completare le operazioni di movimentazione sui containers. Il Capitolo 5 investiga gli effetti della lunghezza dell'orizzonte di pianificazione nella gestione operativa delle risorse umane e, risolvendo istanze numeriche derivate dai terminali in studio, dimostra che l'impiego in *rolling horizon* di un orizzonte di pianificazione bi-giornaliero è in grado di produrre una più efficiente allocazione del personale rispetto all'orizzonte giornaliero standard. Il Capitolo 6 propone e testa diversi scenari di flessibilità del lavoro, al fine di analizzare gli effetti che una maggiore flessibilità comporterebbe in termini di un impiego più efficace delle risorse a disposizione e una conseguente riduzione dei costi operativi. Il Capitolo 7 descrive i modelli logit multinomiali formulati con l'obiettivo di: 1) individuare le determinanti strategiche nella scelta di un sistema operativo portuale; 2) verificare la possibilità di stabilire una relazione empirica tra la rigidità dei regimi di lavoro esistenti in alcuni contesti portuali e la tendenza verso l'automazione emersa nel corso dell'ultimo ventennio. L'applicazione fornisce interessanti indicazioni sui fattori che strategicamente motivano la scelta dei sistemi operativi adottati nei CT europei. Infine, il Capitolo 8 conclude la tesi discutendo alcuni limiti della ricerca e fornendo indicazioni per sviluppi futuri.