THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Developing a Value Proposition of Maritime Ergonomics

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ABSTRACT

There is a large body of knowledge available on the importance of ergonomics for successful (and unsuccessful) systems. Domain specific handbooks, guidelines and standards can be found also for the maritime industry. Yet, the deteriorating figure of maritime casualties and the high incidence of occupational accidents suggest this knowledge is not utilised to its full potential.

Emphasis in this thesis was given to the knowledge base of ergonomics in vessel design and operation. Specifically, the aim was to develop a value proposition of maritime ergonomics, positioning the potential core values of ergonomics that can be delivered to stakeholders within and outside the maritime transport system. This project has therefore taken an exploratory qualitative approach.

Seven studies have been performed, structured around three themes: maritime ergonomics, the effects of maritime ergonomics on operational performance, and the development and transfer of ergonomics knowledge. The methods used were mainly literature studies, individual and focus group interviews, observation and case study.

The results of the studies show a link between ergonomics and the value creating process in the maritime transport system. The developed value proposition describes the value for the employee in terms of improved health and well-being, learning, performance, skill discretion and independence in life. Values for the company include increased operational performance and flexibility, advantages in recruiting and retaining personnel and organizational learning. Values for the sector include competitive strength, attractiveness of work and increased organizational learning across the industry. Values for the society include reduced costs for health care and social security, reduced environmental impact, and a sustainable working life.

To conclude, these results can be seen as a first step to make visible the effects of ergonomics management on overall systems performance in the maritime domain. Suggestions for further work include complementary studies to investigate the feasibility in early crew participation and incorporating ergonomics methods and techniques in the toolboxes of naval architects and other system builders.

Keywords: Ergonomics, human element, participatory ergonomics, shipping, operational performance, value proposition, maritime economics, socio-technical systems.

PREFACE AND ACKNOWLEDGEMENT

This thesis is the fruit of a long love of ships of every kind and an interest in the welfare of the men and women who sail the seven seas in them. The work behind it is in many ways inspired by the ancient Norse writing Konungs Skuggsjá from around 1250. It is written as a dialogue in which a father gives his son advice on how to live a good life, in both a moral and practical sense. The writing starts with a conversation on how to become a successful merchant and one passage especially made an impression on me:

> *'Always buy shares in good vessels or in none at all. Keep your ship attractive, for then capable men will join you and it will be well manned.'*
> Konungs Skuggsjá (reprinted in Larsen, 1917:84)

This advice seemed so obvious in all its simplicity. Why should this not be true of the maritime industry of today?

In 2008, when I began my PhD studies at the department of Shipping and Marine Technology, I returned to this passage. With one foot in marine engineering and the other in ergonomics, I set out to investigate how ergonomics can be used to keep a ship attractive and well manned in order to generate good business. The academic journey has been different from any previous one I have made on the seven seas and I could never have reached my destination without help.

In the words of Woodrow Wilson; I have used not only all the brains I have, but all I can borrow.

First and foremost, I want to thank all informants for kind and committed participation in my research work. Without you, I wouldn't have anything to present here!

I would like to express my gratitude to my examiner Professor Olle Rutgersson, Chalmers, Department of Shipping and Marine Technlogy, who enabled this journey by signing me on and securing funding from VINNOVA, the Swedish Government Agency of Innovation Systems, and LIGHTHOUSE, the Swedish competence centre in maritime education and research.

I have had the great privilege to be guided by several supervisors through various stages of my PhD project: Associate Professor and Master Mariner Margareta Lützhöft at Chalmers, Department of Shipping and Marine Technology, Professor Anna-Lisa Osvalder at Chalmers, Department of Product and Production Development, Professor Paula Liukkonen at Stockholm University, School of Business, and PhD Linda Rose at Royal Institute of Technology, School of Technology and Health. Sincere thanks to all of you for your patience, wisdom and willingness to share your time and knowledge with me. Thank you Anna-Lisa for trusting in me.

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I am thankful for the opportunities I have had to continually expand my perspectives by working and co-authoring together with so many brilliant researchers: Associate Professor Margareta Ljung, Lic Eng Mathias Magnusson, PhD Cecilia Berlin and PhD Lars-Ola Bligård. Not only did we get our papers published, we have had plenty of fun with sugar and skunks during the process. Let's do it again!

In addition, many wonderful colleagues at Chalmers, too numerous to mention, have provided a stimulating and supportive work environment, made me laugh and made me run. I have truly treasured our invigorating *fika* moments on the 5^{th} floor and the variety of topics discussed. Special thanks are due to my roomies PhD Carina Rislund and MSc Helena Strömberg. We have shared so much more than just an office. Thank you for endless hours of debriefing, stimulation, reflections, proof-readings and valuable comments that have challenged me and helped improve my work.

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Thank you also Jörgen Språng for allowing me to use your wonderful photographs.

Last, but in no way least, I would like to direct a heartfelt thanks to my family for your endless support and unconditioned love.

Peter, my unfailing climbing partner in the mountains of life, this thesis is for you.

Cecilia Österman
Gothenburg, November 2012

LIST OF APPENDED PAPERS

This thesis is based on the work described in the following appended papers:

Paper I Österman, C; Rose, L; Osvalder, A-L (2010)
Exploring Maritime Ergonomics from a Bottom Line Perspective.
WMU Journal of Maritime Affairs 9 (2), 153–168.

Paper II Österman, C; Osvalder, A-L (2012)
The human element in maritime logistics.
In D-W Song & P Panayides (Eds), *Maritime Logistics – Logistics Management of Shipping and Ports* (pp. 59–74). London: Kogan Page.

Paper III Österman, C; Rose, L (2012)
Assessing financial impact of maritime ergonomics on company level: a case study. Submitted for approval to *Maritime Policy & Management*.

Paper IV Österman, C (2012)
Performance influencing factors in maritime operations.
In B Lemper, T Pawlik & S Neumann (Eds), *Human Element in Container Shipping* (pp. 87–104). Frankfurt am Main: Peter Lang GmbH Internationaler Verlag der Wissenschaften.

Paper V Österman, C; Osvalder, A-L (2012)
Developing a training course for systematic review of ship drawings from a work environment perspective. Submitted for approval to *Educational Action Research*.

Paper VI Österman, C; Berlin, C; Bligård, L-O (2011)
Enabling end-user participation in ship design. Proceedings of the 43rd Annual Nordic Ergonomics Society Conference – Wellbeing and Innovations Through Ergonomics, Oulu, 18–21 September, 2011.

Paper VII Österman, C; Magnusson, M (in press)
A systemic review of shipboard SCR installations in practice. Accepted for publication in *WMU Journal of Maritime Affairs*. Available online at DOI: http://dx.doi.org/10.1007/s13437-012-0034-1

DISTRIBUTION OF WORK

The contribution of Cecilia Österman to the appended papers in this thesis is as follows:

I. Österman initiated the paper, performed data collection and analysis and had the main responsibility for writing the paper in collaboration with co-authors Rose and Osvalder.

II. Österman developed the theoretical framework, performed the literature review and wrote the paper. Osvalder contributed as reviewer.

III. Österman initiated the paper, performed data collection and analysis and had the main responsibility for writing the paper in collaboration with Rose.

IV. Österman initiated the paper, performed the literature review and wrote the paper.

V. Österman initiated the paper, performed data collection and analysis and had the main responsibility for writing the paper. Osvalder contributed as reviewer.

VI. Österman contributed to the ideas presented and participated in the planning of the investigation, data collection and analysis. Österman had the main responsibility for writing the paper in collaboration with Berlin and Bligård.

VII. Österman contributed to the ideas presented and participated in the planning of the investigation, data collection and analysis. Österman had the main responsibility for writing the paper in collaboration with Magnusson.

ADDITIONAL SCIENTIFIC PUBLICATIONS

Österman, C
(2012)
Knowledge ergonomics – linking islands of knowledge to promote sustainable shipping
Proceedings of the 44th Annual Nordic Ergonomics Society Conference – Ergonomics for Sustainability and Growth, Saltsjöbaden, Sweden, 19–21 August 2012.

Österman, C & Magnusson, M
(2012)
A systems perspective on practical experiences of marine SCR installations
Proceedings of the 2012 International Research Conference on Short Sea Shipping, Lisbon, 2–3 April, 2012.

Österman, C
(2011)
Engaging safety delegates in a collaborative ship design process
Proceedings of the 4th FALF national conference on worklife science, Luleå, 15–17 June, 2011.

Österman, C
(2010)
Ergonomics: An uncharted route to improved overall systems performance in shipping
Thesis for the degree of Licentiate of Engineering, Chalmers University of Technology, Gothenburg.

Österman, C, Ljung, M, & Lützhöft, M
(2009)
Who Cares and Who Pays? The Stakeholders of Maritime Human Factors
Proceedings of the RINA Conference on Human Factors in Ship Design and Operation, London, 25–26 February, 2009.

Österman, C & Lützhöft, M
(2008)
Another day, another dollar – Cost-benefit of Human Factors in Shipping
Proceedings of the 27th European Annual Conference on Human Decision-Making and Manual Control, Delft, 11–13 June, 2008.

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1 INTRODUCTION

This chapter gives an introductory background and aim of the research work presented in this thesis. It is followed by a brief account of the appended papers, delimitations of the work, and ends with an explanation of occurring abbreviations, acronyms and terminology.

1.1 Developing a value proposition of maritime ergonomics

The main theme of this thesis is the value proposition of maritime ergonomics, positioning the potential core values of ergonomics that can be delivered to employees, customers, and other stakeholders within and outside the maritime transport system. Value propositions are not just about selling. They are part of operational strategy, guiding many levels of an organization towards satisfied constituents and sustainable value creation (Barnes et al., 2009). Similarly, ergonomics is not only *'for design of chairs'* (Helander, 2000). It is the science and application of fitting systems, tools and tasks to the human, in order to optimise human well-being and overall system performance (IEA, 2012). As this thesis describes, the area of ergonomics can be a useful tool in the development and implementation of operational strategies in the maritime domain, ultimately contributing towards safe, efficient and sustainable sea transports.

1.2 Background

The maritime transport system is the life-blood of the world trade and plays a key role in the global economy and in supporting economic growth. While basic economics of commercial shipping have remained largely unchanged through history – shipping has been driven by the laws of supply and demand since the early sea trade in Mesopotamia 5 000 years ago – the ships and commercial infrastructure have gradually evolved towards the tightly knit global industry of today (Stopford, 2009). Continuously, the world fleet has expanded in number, size and sophistication. Technological developments of hull, propulsion and cargo handling systems have increased speed and improved capacity, versatility and reliability of maritime transports. Mechanization, automation and communications technology have made many manual tasks redundant, enabling efforts to perfect crew size and composition in order to curtail operations costs (Ding and Liang, 2005).

However, there is yet an area of potential to develop in the effort to optimise maritime operations: occupational ergonomics and the interplay of human, technology and organization in the process of design and organization of tasks, technology and work environments. There is an obvious risk of sub-optimisations if decisions are made and measures are taken unilaterally, instead of adopting a wider perspective that takes more than one aspect into account. Single efforts may counter-act each other and conflict with other interests. As technological systems increase in complexity, the gap between the human operator and the technical system tends to increase as well. Increased automation and the introduction of new technology have reduced transparency of work operations on board. Out-of-the-loop unfamiliarity, automation induced errors, complacency, behavioural adaptation and loss of skills are but a few common problems associated with the introduction of novel technology (Lee, 2006, Stanton et al., 2010, e.g.

Kaber and Endsley, 1997). These issues have also been observed within the maritime domain (e.g. Lee and Sanquist, 2000, Lützhöft and Dekker, 2002). The transformation of technologies place new demands on the human operators at work who must control, diagnose and solve new kind of situations. We need to learn faster, more actively, but also ethically in order to be economically, ecologically and socially sustainable in a global world (Zuber-Skerritt, 2001).

There is a large body of generic knowledge available on the importance of ergonomics to successful (and unsuccessful) systems. Domain specific ergonomics handbooks, guidelines and standards can be found also for the maritime domain (e.g. Grech et al., 2008, Ross, 2009, Rumawas and Asbjørnslett, 2010). Yet, it seems this knowledge, and the application of ergonomic principles and methods in practice, is not utilised to its full potential. Recent statistics show deteriorating figures for maritime casualties (IUMI, 2012), and despite significant changes in work tasks, towards more monitoring and administrative work, the industry is still suffering from a high level of occupational accidents (Rodríguez and Fraguela Formoso, 2007, Hansen et al., 2005, Ellis et al., 2011). Further, occupational mortality and morbidity rates for seafarers remain among the highest for all occupations (Roberts and Marlow, 2005). This high incidence of occupational accidents and injuries means that many individuals are afflicted with aches, pains and sometimes lifelong disability and relegation from the labour market, but it also means disruptions of output and heavy expense to businesses and community.

In a world of competing financial priorities, ergonomists and work environment specialists have apparently not succeeded in selling the systems approach of ergonomics as a tool towards improved overall systems performance and employee well-being (Dul et al., 2012). Rather, there are islands of knowledge and pockets of practice that still remain to be linked. In order to achieve better communication between ergonomists and major stakeholders in maritime operations, efforts have to be made towards an increased use and understanding of the relationship between commercial value generation and ergonomics.

1.3 Research aim

The aim of the work presented in this thesis is to develop a value proposition of maritime ergonomics, describing the core values of a systematic ergonomics management from individual, organizational and societal perspectives. In order to achieve the aim, the work has been designed to study the following research topics:

1. Maritime ergonomics – investigating the key issues in the maritime domain

2. Effects of ergonomics – investigating the effects of ergonomics on operational performance in the maritime domain on individual, company and societal level respectively

3. Knowledge of ergonomics – the development and transfer of ergonomics knowledge between stakeholders in the maritime domain.

The overall aim is to increase the knowledge base of the value of ergonomics in the maritime domain, thus contributing towards improved working conditions for seafarers in a safe and sustainable maritime transport system.

1.4 Papers in this thesis

The seven papers included in this thesis describe different parts of the research work. Figure 1 illustrates the relationship between the research topics and the studies presented in the papers. The purpose and research approach of the studies are summarised in Table 1.

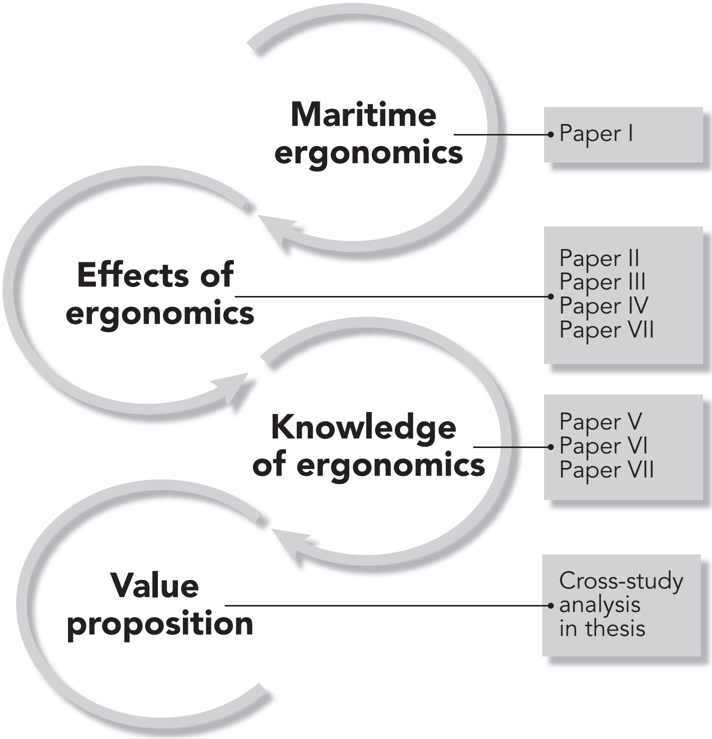

Figure 1 *Relationship between the research topics and the papers.*

The research work was initiated with an investigation into the concept of ergonomics in theory and practice (Paper I), and how ergonomic factors can influence human and operational performance within the maritime domain (Papers II, III, IV and VII).

It is followed by the studies presented in Papers V, VI and VII that concern the topic of knowledge development and transfer within maritime ergonomics and specifically crew participation when designing new workplaces or introducing new technical systems on board.

By way of conclusion, a cross-study analysis (chapter 5.4) leads up to the development of a value proposition of maritime ergonomics.

Table 1 *Summary of purpose and research approach*

Paper	Purpose	Approach and methods
Paper I *Exploring maritime ergonomics from a bottom line perspective*	To explore the concept of maritime ergonomics, from researcher and practitioner perspective. The paper also includes a review of methods for estimating economics of ergonomics in other domains and a survey investigating the potential use of any method by Swedish shipping companies.	Explorative study. Literature review, semi-structured individual interviews on maritime ergonomic factors, and structured individual telephone interviews on the estimation of economic effects. Meaning condensation and categorisation.
Paper II *The human element in maritime logistics*	To explore overall system performance and well-being in a maritime context, and how the concepts of productivity, efficiency and quality can be operationalized and related to human element issues.	Analytical review. Literature review.
Paper III *Assessing financial impact of maritime ergonomics on company level – a case study*	To investigate the availability of the concepts and metrics suggested in Paper II in the setting of a Swedish shipping company.	Retrospective case study. Interviews, content analysis of documents. Meaning condensation and categorisation.
Paper IV *Performance influencing factors in maritime operations*	To investigate important performance influencing factors relevant for maritime operations.	Analytical review. Analysis based on the taxonomy developed by Kim and Jung (2003), classifying the influencing factors into four main groups: human, task, technical system and environment.

Paper	Purpose	Approach and methods
Paper V *Developing a training course for systematic review of ship drawings from a work environment perspective*	To develop a training course seafarer safety delegates in the systematic review of technical ship drawings from a work environment perspective suitable for learners with limited previous experience of technical drawings.	Participatory action research based on problem-based learning methods. Three groups of seafarer safety delegates participated in the study.
Paper VI *Enabling end-user participation in ship design*	To explore possibilities for including seafarers in the ship design process in a cost-efficient manner, and to investigate whether simple representations of a ship bridge can generate valuable information.	Participatory design study investigating the possibility to use 3D-representations as enabler for involving seafarers in a participative design process. Observations, group interviews and questionnaire.
Paper VII *A systemic review of shipboard SCR installations in practice*	To explore the human–machine aspects of installations of selective catalytic reduction (SCR) catalysts to reduce nitrogen emissions from ships. Further, to identify important technical, human and organizational conditions necessary for safe, efficient and sustainable SCR operations.	Retrospective, explorative study. Focus group interviews, individual interviews. Meaning condensation and categorisation.

1.5 Delimitations

The research work presented in this thesis comprises merchant ships covered by the mandatory International Safety Management (ISM) Code (IMO, 2010). The conditions for naval ships, fishing vessels, training ships and so called traditional ships are not covered. The thesis is placed mainly within the freight market (Stopford, 2009), where the actual sea transport services are taking place. Thus, the thesis does not reflect upon, for example, the capital market, financing of ships or asset play (trading in ships as a major source of revenue). Nor does the thesis consider operations strictly related to cargo handling in port.

1.6 Abbreviations, acronyms and terminology

To increase clarity and readability, abbreviations, acronyms and jargon are avoided as far as possible in this thesis. There are however some concepts that are so widely used in the maritime domain that spelling them out would be contra-productive, as well as wordier. For readers less versed in the maritime terminology, table 2 introduces a list of essential terms used in the thesis (sources: Stopford (2009) and SST (2011) unless otherwise stated).

Table 2 *Terminology, abbreviations and acronyms*

Terminology	
Ballast	Sea water pumped into ballast tanks or cargo spaces when the ship is not carrying cargo, to lower the ship in the water.
Charterer	A person or firm who enters into a contract with a shipowner for the transportation of cargo or passengers for a stipulated period of time, i.e. a shipowner's customer.
Classification society	An organisation that establishes and maintains proper technical standards for the construction and classification of ships, supervises their construction and carries out regular surveys of ships in service to ensure continued seaworthiness and compliance with safety standards.
Dry bulk	Coal, grain, minerals, ore, wood products, dry chemicals, edibles etc. transported unpackaged in large quantities in cargo holds.
Liquid bulk	Crude oil, liquefied natural gas (LNG), petroleum, gasoline, liquid chemicals, vegetable oil etc. transported in large quantities in tanks.
Marine or maritime accident	Used as a synonym for marine casualty in order to distinguish from an occupational accident. IMO (2008) defines marine casualty as an event resulting in any of the following: • death of, or serious injury to, a person (N.B. in this thesis referred to as occupational accident) • loss of a person from a ship, loss or abandonment of a ship • material damage to own ship, another ship or marine structure • stranding, disabling or collision of a ship or • severe damage to the environment
Occupational accident	Used as a synonym for work accidents and occupational injuries to distinguish from marine (or maritime) accidents.

Off-hire Period	Period of time during which a vessel under time charter is unable to meet the requirements agreed between the charterer and shipowner due to reasons within the control of the shipowner, e.g. machinery breakdown. During this time, the charterer is not required to pay hire money.
Ship operator	Owner or other operator of ships who enter into a contract with the shipper (the sender) for the transportation of goods.

Abbreviations and acronyms

IACS	International Association of Classification Societies. An organization consisting of the thirteen largest marine classification societies.
ILO	International Labour Organization. The UN agency that deals with international labour standards and decent work for all.
IMO	International Maritime Organization. The UN agency that deals with maritime affairs.
ISM	The International Safety Management Code adopted by the IMO is an international standard for the safe management and operation of ships and for pollution prevention.
MLC	Maritime Labour Convention. Prescribes minimum requirements for seafarers, conditions of employment, facilities on board, health protection, welfare and social security protection.
MSD	Musculoskeletal disorders. Disorders or injuries affecting muscles, tendons and joints.
NOx	Nitrogen oxides. Commonly refers to NO and NO_2
Paris MoU	Paris Memorandum of Understanding. Regional co-operation group of maritime administrations in Europe and the North America that performs Port State Controls.
PSC	Port State Control. An inspection of foreign ships in national ports to verify that the ship is manned, operated and equipped in compliance with applicable international law.
RoRo	Roll on, roll off vessels that are equipped with one or more ramps, allowing cargo to be rolled on and off.
SCR	Selective catalytic reduction. A method for converting nitrogen oxides from combustion gases into nitrogen and water with the aid of a catalyst.
SMS	Safety Management System. A structured and documented system enabling effective implementation of a shipping company's safety and environmental protection policy.
SOLAS	The IMO International Convention for the Safety of Life at Sea. Specifies minimum standards for the safe construction, equipment and operation of ships.

2 FRAME OF REFERENCE

In this chapter, the thesis' theoretical foundation is presented. The chapter is initiated with a section on systems theory and the socio-technical system, followed by a description of the concepts of ergonomics, human factors and human element. The chapter ends with a description of the maritime transport system with its economic drivers and regulatory regimes.

2.1 Systems theory and the socio-technical system

The systems view constitutes an established analytical view with some definite characteristics. A common core is that a system consists of a number of parts that are coordinated to achieve certain goals.

The long history of systems thinking can be traced back to early Oriental and Occidental philosophers' holistic understanding of the world. The interrelatedness of all life and manifestation is a central principle in Taoism and Buddhism where the Universe, Earth and mankind are equal, forming an interconnected whole. Similarly, the ancient Greek philosophers Aristotle and Plato applied systems ideas across various domains, subsequently serving as inspiration to later Western philosophers such as Spinoza, Hegel and Marx (Jackson, 2000).

In Aristotle's philosophy, *holon* – the whole – is characterised not only by it parts, but by the relations between the parts as well (Ropohl, 1999). Just as an eye only can see when connected to a body, the parts of a system only obtain meaning in terms of the purpose of the whole. In his Socratic dialogue *The Republic*, Plato used a becoming allegory of a ship when comparing the art of governing a state and its people to that of navigating and steering a ship (Plato, 375 BC). The seafaring metaphor *kybernetes*, which principally means steering a vessel, used here by Plato was later picked up by the American mathematician Norbert Wiener, who in 1948 introduced Cybernetics as the science of '*control and communication in the animal and the machine*' (Wiener, 1948). Modern-day cybernetics can be viewed as a facet of the systems approach and is applied in a wide range of studies of the function of physical, economic, cognitive, and social systems of control.

A contemporary to Wiener, the Austrian biologist Ludwig von Bertalanffy is said to be the first to establish systems thinking and its underlying principles as an intellectual movement (Emery, 1969). As a biologist, von Bertalanffy realised that the closed systems studied by physicists assuming that everything that affects the system is included in the model, is not feasible for most practical phenomena. In contrast, an open system constantly interacts with other systems outside of themselves.

> '*We find systems which by their very nature and definition are not closed systems. Every living organism is essentially an open system. It maintains itself in a continuous inflow and outflow, a building up and breaking down of components, never being, so long as it is alive, in a state of chemical and thermodynamic equilibrium but maintained in a so called steady state which is distinct from the latter.*'
> (von Bertalanffy, 1968).

Von Bertalanffy called it a general science of '*wholeness*' applicable to the various empirical sciences (von Bertalanffy, 1968). He argued that knowledge of the elements within a system is not sufficient without knowledge of the system boundaries towards the environment and how the elements in the system are interrelated.

Another forerunner of systems theory, the American philosopher C.W. Churchman was allegedly the first to incorporate ethical aspects in systems science (Ulrich, 1988). In his influential book Challenge to Reason (1968), Churchman reflects upon the epistemological and ethical challenges of the systems idea:

> *How can we create a science which is meaningful, that is, a science that will use reason to provide guidelines to men in the improvement and maturation of their own lives and of social systems? Can there be a science of the ethics of the whole system?* (Churchman, 1968)

In order to be able to understand and analyse a system, Churchman argues that there are five fundamental aspects to consider:

1. The tasks and goals that the system is to achieve

2. The environment in which the system operates

3. The system's resources that can be used to fulfil the tasks

4. The system's parts, activities, goals and functional validity. What do the parts contribute with to the system as a whole?

5. The management and coordination in the system, and how it is effected.

The essence is not to know all there is about the studied system, but rather to understand the possible implications of our lack of comprehensive knowledge. It is because we never know enough that understanding and critical judgment becomes essential, from an intellectual as well as a moral point of view. Uncertainty about the effects of our actions on the system as a whole does not dispense us from moral responsibility (Churchman, 1968).

2.1.1 Socio-technical systems theory

A major component of many systems is people, acting as users, operators, maintainers and so forth. Even a highly automated system requires people – in any case to start, stop, monitor and occasionally perform service and maintenance on equipment in the system. This interrelatedness of people and technology in an organization or the society as a whole is commonly referred to as socio-technical systems theory. The approach was developed largely at the Tavistock Institute of Human Relations and their studies from British coal mines (Emery and Trist, 1960). The point of departure for socio-technical systems theory is the alleged lack of mutual understanding of the technical society. Engineers are said to ignore the social concerns of their work, and social scientists to ignore technology. In this respect, a systems model can be a tool to bring both sides together and portray both social and technical phenomena; the technization of society and the socialization of technology (Ropohl, 1999).

Socio-technical systems theory views organizations and work groups as open systems with social, technological and economic dimensions, fitted into their environment. When designing a work organization, all three elements should be jointly optimised to ensure optimisation of the whole, even if this requires a less optimum state for any of the elements (Jackson, 2000). In order to facilitate understanding of the relationships between people and technology, Vicente (2004) offers the Human-Tech ladder (Figure 2) as a conceptual roadmap. The concept of technology is here widely defined and includes both physical, but also less tangible aspects of the system (*'soft elements'*) such as work schedules, information, team responsibilities, staffing, and legal regulations.

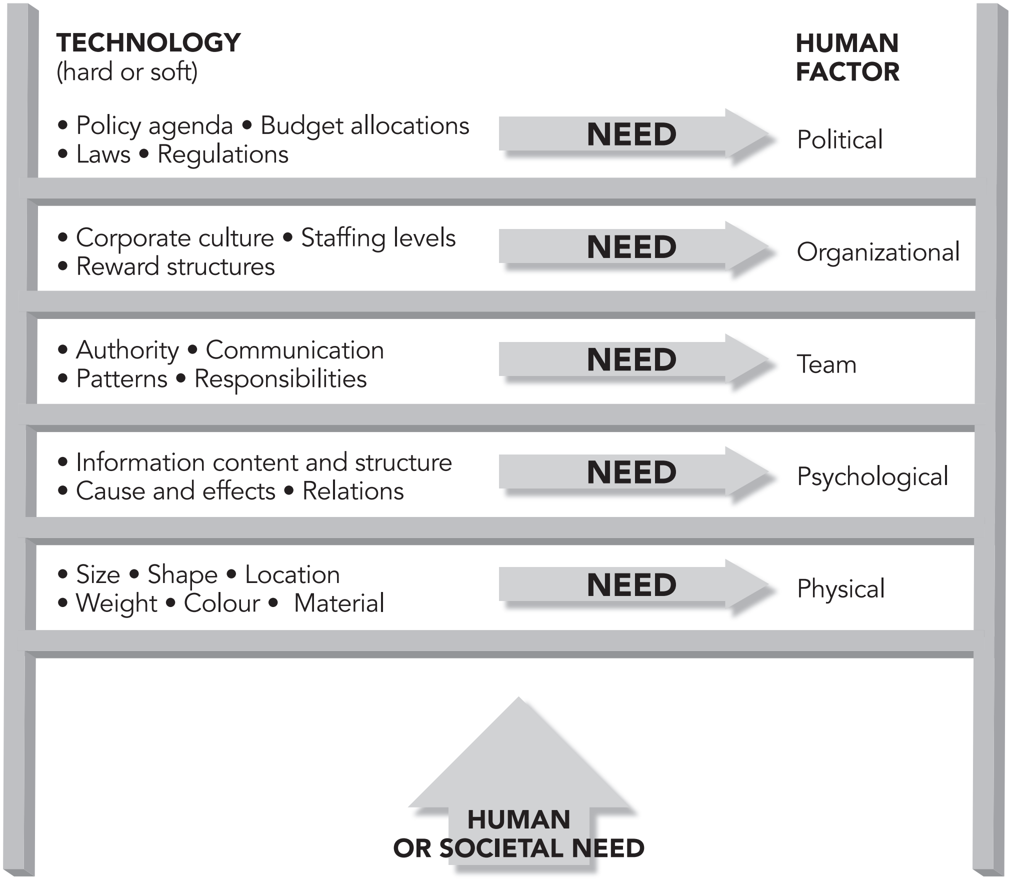

Figure 2 *The five levels of human factors (adapted from Vicente, 2004)*

As illustrated in the ladder, Vicente argues that each design should begin by understanding a human or societal need. Then, technology should be tailored to fit basic human physical and psychological abilities and limitations. Moving up the ladder, the same approach is applied to teamwork, organizations and political systems as far as necessary for the design in question.

Various models have been proposed to define the elements of a socio-technical system, describing the systems either vertically, functionally or by domain (see for instance Carayon, 2006 for a comprehensive review). Common for most, if not all, of these models is that they underline the need to understand the interactions between people and elements of the system, as well as the interactions with the system's wider environment. The interactions can be of physical, cognitive and psychosocial nature, and encompass various system levels from micro-ergonomic issues all the way to macro-ergonomic issues.

2.2 Science and practice of ergonomics (or human factors)

The science of ergonomics (or human factors) is multi-disciplinary systems and design oriented, sometimes referred to as the science of *fitting the task to the human* (Kroemer and Grandjean, 1997). It implies the design of tasks, artefacts, systems and environments to be compatible with our physical and mental needs, abilities and limitations (Chapanis, 1996).

2.2.1 The evolution of ergonomics

The word ergonomics derives from the Greek *ergos* (work) and *nomos* (law, or system) and can be translated as the science of work. Ergonomics as a scientific discipline was first introduced in 1857 by the Polish scientist Wojciech Jastrzębowski , who proposed a broad scope of human activity, including labour, entertainment, reasoning and dedication (Jastrzębowski, 1857 reprinted in Karwowski, 2006).

Present-day ergonomics has fused from the North American human factors, developed largely to enhance systems performance in a military setting, and the European industrial applications for design of workstations and industrial processes (Helander, 1997). The broad, interdisciplinary scope of the field contributes to the challenge of defining and communicating ergonomics, since it can be many things to many people (Young et al., 2010). However, most professionals in the discipline regard ergonomics and human factors as equivalent (Chapanis, 1996), an equivalence that is manifested in the International Ergonomics Association (IEA) definition of ergonomics:

> *'Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance' (IEA, 2012).*

IEA's definition demonstrates a holistic approach embracing all aspects of human work, indicating both an individual and social aim (human well-being) as well as an organizational and economic aim (overall system performance). Thus, ergonomics is not a goal in itself, but can rather be viewed as a way to ensure goals of improved system effectiveness, safety, ease of performance and the contribution to overall human well-being and quality of life (Karwowski, 2005).

Domains of specialisation within ergonomics embody deeper competencies, often grouped in physical, cognitive and organizational ergonomics (IEA, 2012). Physical ergonomics refers to anatomical, physiological, anthropometric and biomechanical characteristics related to human activity. Relevant topics include working postures, manual handling, repetitive movements, work-related musculoskeletal disorders, workplace layout, product design, safety and health. Physical ergonomics is also concerned with how the physical work environment (e.g. noise, vibrations, light, climate and hazardous materials) can affect human performance. Physical factors in the work environment can interact with and aggravate risks of musculoskeletal disorders and have an adverse effect on mental health. Knowledge of the effects physical ergonomic factors have on humans is important when designing tools, machines, work tasks and environments to avoid harm and ensure necessary prerequisites for good performance. The human body is made for variation and motion, so an appropriate mixture of movements, loads and recovery is needed to sustain the functions of the body. While it might be readily understood that heavy loads and awkward working postures can have destructive effects on body tissue, it is equally important to avoid too low and static loads. Sedentary work, such as monitoring for a prolonged period, is unfavourable for the circulation and locomotor organs (Bernard, 1997, Wahlström, 2005).

Cognitive ergonomics is concerned with mental processes such as perception (the process of interpreting information from our senses), cognition and motor response (IEA, 2012). It can be described as the science of designing tasks, artefacts and systems to fit the human mind. Relevant topics of cognitive ergonomics include mental workload and performance, decision-making, human error, human reliability, work stress, and training. These topics can all relate to operator performance in a human–machine system (Wickens and Hollands, 2000).

Organizational ergonomics establish the organizational context and is concerned with the optimisation of socio-technical systems, including their organizational structures, policies, cultures and processes for communication and decisions on who knows what, who will do what and who has done what. (IEA, 2012). Relevant topics include communication, human resource management, teamwork, design of working schedules, participatory design, co-operative work, organizational culture, telework, and quality management. Within the specialisation of organizational ergonomics it is argued that the interaction of four major socio-technical system elements must be considered in the design of effective work system structures: the external environment, the technical sub-system, the internal environment, and the personnel sub-system (Hendrick and Kleiner, 2002). Using a socio-technical systems approach, organizational ergonomics can be applied to the development of training systems, risk management, introduction of new technology, organizational change projects, job design, and more.

2.2.2 Work environment economics

Poor workplace ergonomics is known to have negative monetary and other effects for individuals, companies and for the society as a whole. At an employee level, poor working conditions can lead to accidents and illnesses that affect their income, lead to short term and long term costs such as treatments and rehabilitation and can affect their lifetime wages (Hendrick, 2003, Leigh et al., 2000, Mossink and De Greef, 2002). On company level, the relationship between ergonomics and operational performance have been demonstrated in terms of increased production (Abrahamsson, 2000, De Greef and Van den Broek, 2004, Niemelä et al., 2002), improved level of quality (Axelsson, 2000, Eklund, 1995, Falck, 2009), and reductions in work-related musculoskeletal disorders, personnel turnover and absenteeism (Goggins et al., 2008, Mathiassen et al., 1996).

At societal level, the direct and indirect costs associated with occupational accidents have been estimated to 1–3 per cent of gross national product in the EU member states (Mossink and De Greef, 2002) and about 3 per cent of the US gross national product (Leigh et al., 2000). These societal costs consist of the total loss of resources and productive capacity, and reduction of welfare and health (AV, 2010).

A framework originally developed by Neumann and Dul (2010) and further advanced by Rose, Orrenius and Neumann (in press) situates the work environment embedded within a company's operations system. Within the operations system, the work environment will have both system effects, on productivity, efficiency or quality as previously mentioned, as well as human effects, on competence, employee's health and safety etc. The framework describes how accidents and disorders generate direct costs for sick leave, insurance, and medical expenses, and suchlike, which affect the financial outcome.

Less visible are the indirect impacts of the work environment on the operations system, e.g. when employees underperform due to pain caused by strenuous working conditions. Rose et al. argue that in general, the indirect costs within the operations system are considerably more significant than the more visible, direct costs.

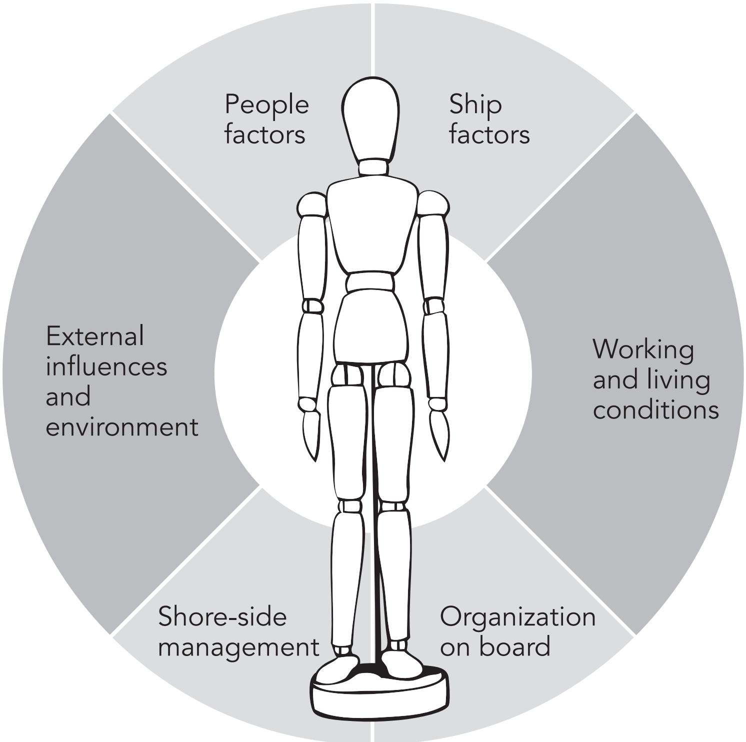

Figure 3 *An overview of factors that have an impact on the human element*

2.2.3 Human element

Within the maritime domain it is common to use the term human element when referring to the interaction of human, technology and organization. In November 1997, the International Maritime Organization (IMO) Assembly adopted Resolution A.850 (IMO, 1997) that defines the human element as:

> *'a complex multi-dimensional issue that affects maritime safety and marine environmental protection. It involves the entire spectrum of human activities performed by ships' crews, shore based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to cooperate to address human element issues effectively.'*

The Resolution further acknowledges the need for increased focus on human-related activities in the safe operation of ships and requests the IMO Committees for maritime safety (MSC) and maritime environment protection (MPEC) to take the human element into account when proposing new or revised instruments and proposals.

Over the years, the role of human element in maritime safety has evolved from what Reason (2000) labels the *person approach*, that focuses on the unsafe acts of people at the sharp end, to the *system approach*, that concentrates on the conditions under which individuals work. As a result, the revised IMO guidelines for investigation of marine casualties and incidents (IMO, 2000) provide a general overview of factors that have a direct or indirect impact on the human element (Figure 3). The purpose of the guidelines is to ensure a system approach and increased awareness of the role human element plays in all aspects of marine design, management, operations and maintenance.

People factors include, but are not limited to, skills, knowledge (outcome of training and experience) and mental and physical condition. Ship factors include design, state of maintenance and availability and reliability of equipment. Working and living conditions include design of working, living and recreation areas and equipment as well as opportunities for recreation and adequacy of food.

Organization on board includes factors such as division of tasks and responsibilities, crew composition, manning level and workload, while shore-side management concerns safety and recruitment policies, management commitment to safety and ship-shore communication.

External influences and environment factors include sea and weather conditions, port and sea traffic conditions, various stakeholder organizations, and national and international regulations and inspections.

2.3 The maritime transport system

In order to understand a complex socio-technical system such as the maritime transport system, it is necessary to apprehend the complex web of relationships and interdependencies, as well as the continuously changing nature of the people and technologies in the system. The global maritime transport system connects the world regions, nations and cultures and is of fundamental relevance for world trade and economic growth.

In January 2011, the world merchant fleet reached almost 1.4 billion deadweight tons (UNCTAD, 2011), serving more than 90 per cent of the global trade (IMO, 2012). Vessels vary greatly in size and types and are generally grouped in five aggregated categories described in Table 3 (derived from IHS Fairplay (2012) and UNCTAD (2011)).

Table 3 General grouping of vessel categories

Group	Description
Oil tankers	For bulk carriage of crude or refined petroleum products.
Bulk carriers	For carriage of bulk dry cargo of a homogeneous nature, such as iron ore, coal, grain, fertilizers, or wood chips.
General cargo ships	For carriage of various types of dry cargo such as refrigerated cargo, specialised cargo, or roll on-roll off (ro-ro) cargo.
Container ships	For carriage of containers, typically 20 or 40 foot container units.
Other ships	Other tankers, gas carriers, passenger ships, combined ro-ro and passenger ships (ro-pax), tugs, barges, fishing ships, offshore anchor handling and supply ships.

As illustrated in Figure 4, the task of the sea transport system, the transport service assignment principally consists of a physical and an immaterial part. The physical part involves the actual movement and handling of goods (or passengers), while the immaterial part largely concerns information transfer between the various actors in the transport system, but also the quality and safety of the transport (Lumsden, 1998).

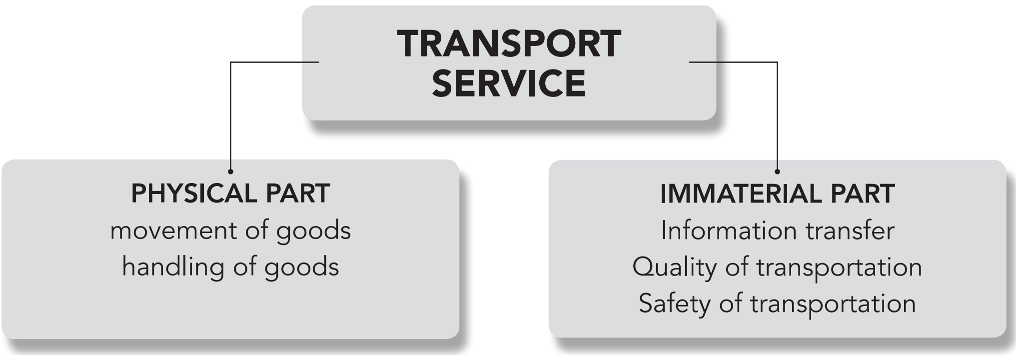

Figure 4 *The principal parts of a transport service (adapted from Lumsden, 1998)*

2.3.1 Maritime economics

The shipping industry operates in a business-to-business (B2B) context involving a number of service activities. The primary task is to transport goods and people around over deep seas and along inland waterways, but in the rapidly globalising market place, maritime transports have evolved into globally networked and rationalised distribution systems. Many shipping companies today offer a complete logistics solution, a one-stop-shop for their customers.

Maritime economics as a branch of economic theory has developed through the study of transport economics. As for business in general, maritime economics is largely about supply and demand and depends heavily on worldwide macroeconomic conditions. Developments in the world economy and merchandise trade are driving developments in seaborne trade. Principally, the level of demand depends on the world economy, commodity trades, average distance, political events and transport costs. Supply depends on the size of the world fleet, productivity, shipbuilding production, scrapping of ships and freight rates (Stopford, 2009). In a short perspective, supply can be influenced by laying up vessels or changing vessel speed. In a longer perspective, supply can be influenced by putting newbuildings into service or breaking up old vessels. Supply can also be altered by technological change and changes in the cost of key inputs such as fuel prices.

A classic example of how external factors can affect demand and supply in shipping are the closures of the Suez Canal during the Suez Crisis in 1956–1957 and from the beginning of the Six Day War in 1967 until 1975. The Suez Canal provides the shortest sea route between Asia and Europe and handles around 8 per cent of world trade (SCA, 2012). The alternative route around Cape of Good Hope increases the shipping distance for a typical East-West passage such as from Jeddah in the Arabian Gulf to Rotterdam with some 41 per cent. The shortage of supply that followed the increase in ton-miles during these closures resulted in rising freight rates and contracts were signed by sea transport buyers for chartering of ships which had not yet been built. During the prevailing strong market times, many newbuildings were ordered, which in turn lead to an oversupply and falling freight rates when the Canal was reopened again (Stopford, 2009).

Another recent example is during the global recession in 2009 when many ship operators adopted 'slow steaming' strategies to absorb surplus capacity and in response to volatile fuel costs. In order to uphold the same level of service while cutting speed, extra vessels can be added to the string. Cycles like this are significant for the shipping market and since the demand changes faster than the supply, freight cycles are generally irregular. Because troughs generally last longer in time than peaks, there is a strong focus on cost-cutting rather than revenue in maritime economics.

Veenstra and Ludema (2006) claim that success in the shipping industry depends on entrepreneurship, market insight and possibly a certain lack of risk aversion. But success also depends to a large extent on the capabilities of the main asset: the ship. Since a shipowner considers most costs as constant, the margin is determined by the *'earnings potential'*; how much revenue can be earned with a ship (Veenstra and Ludema, 2006). The main items of the earnings potential are a ship's cargo carrying capacity, speed and versatility, and can be expressed in various rations such as dollar per ton, dollar per day or dollar per ton-miles. The versatility refers to the ship's suitability in picking up different cargoes in different areas if the shipowner wants to avoid being tied to specialised markets that might be volatile or irregular.

During its lifecycle, a merchant vessel trades in the four markets of shipping (Stopford, 2009): the newbuilding market where the ship is ordered, the freight market where the ship is operated; the sale and purchase market is the second-hand market for ships; and the demolition market where the ship is recycled. These four shipping markets are positioned in a surrounding world of regulatory regimes, insurance companies, classification societies, and third party stakeholders on local, regional and global level.

2.3.2 Regulatory regimes

The shipping industry has been viewed by economists as the model of perfect competition since the days of the Dutch philosopher Hugo Grotius and the publication of *Mare Liberum* (The Free Sea), in 1609. This apparent freedom of action does, however, bring some challenges. The range of organizations and decision-making structures involved in the shipping industry can be illustrated by the example of the ill-fated oil tanker *Prestige* that broke up and sank off the north cost of Spain in 2002, spilling 64 000 tonnes of oil. The Bahamas-flagged *Prestige* was built in Japan, owned by a Liberian company, managed by a Greek operator, chartered by a Russian-owned Swiss-based oil trader, classed by American Bureau of Shipping and insured by the mutual London P&I Club. On her last voyage, *Prestige* was carrying Russian heavy fuel oil bound for Singapore. The multinational crew consisted of 27 seafarers from Greece, Philippines and Romania, using English as the working language on board.

With such a multitude of stakeholders of different nationalities, the regulation of the shipping industry is inevitably complex with intra- and inter-organizational relationships within and among various members of the global maritime community. These intermediary organizations interact to form both systems of self-governance, and private systems of governance. These systems often overlap, relying in part on the same organizations (Furger, 1997).

Principally, three main regulatory regimes create rules and have the means to enforce them: the Classification societies, the coastal states and the flag states (Stopford, 2009). In addition, there are international conventions on issues where it is considered especially important that all nations have the same laws. The main United Nation bodies that develop and maintain maritime conventions are the International Maritime Organization (IMO) and the International Labour Organization (ILO).

The classification societies

The classification societies are the backbone of the system of self-regulation within the industry. Its history goes back to the eighteenth century when it started as a register grading ships for the London underwriters. Gradually the role of the classification societies has developed and the importance of the contemporary classification certificate has dilated beyond the insurers. The classification societies of today have unfolded into a major technical adviser to both shipowners and governments, and they develop and implement rules and standards regarding the design, manufacture, construction and maintenance of ships.

Thirteen of the most prominent of the classification societies worldwide are members in the International Association of Classification Societies (IACS). The objectives of the association include harmonization of the different rule books and to constitute an interface to other rule-setting organizations, primarily the IMO where IACS has consultative status. Neither IACS nor the individual societies have any legal authority. Their power is a consequence of market forces. The sanction for non-compliance with classification rules is the loss of certificate of classification, which is the basis for charter parties and insurance. Without the certificate it is practically impossible to secure insurance cover, and a vessel without insurance is unable to attract any business or call at most international ports.

The coastal states

With many ships spending their entire economic life travelling between different jurisdictions follows a need for common rules when settling questions on which nation's law applies, and the rights of other nations over the ship. The UN Convention on the Law Of the Sea (UNCLOS) entered into force in 1994. UNCLOS is one of the most comprehensive multilateral treaties ever concluded, limiting national jurisdiction over the seas and aiming at the protection and the preservation of the marine environment (Dixon, 2007). UNCLOS defines the rights of the coastal states by dividing the sea into maritime zones; the territorial sea, the contiguous zone, the exclusive economic zone and the high seas.

Coastal states have the right to pass legislation regarding ship operations in their territorial waters. Several examples of this kind of national or regional incentives are related to the environmental impact from ship operations. One example is the special duty for nitrogen oxides emissions on all ship operations within Norwegian waters introduced by the Norwegian government in 2007 (Toll, 2011), another example is the mandatory ballast water management program for all vessels with ballast tanks who operate within United States waters (USCG, 2012).

Further, coastal states around the world have founded regional co-operation groups in which Port State Control Officers (PSCO) are authorised to inspect and under certain circumstances detain ships. One example is the Paris Memorandum of Understanding (MoU) that is considered to be the worldwide index for flag performance (Paris MoU, 2012a). Paris MoU consists of 27 participating maritime administrations and covers the waters of the European coastal states and the North Atlantic basin from North America to Europe. Another regional incentive is the European Maritime Safety Agency (EMSA) that was set up in the wake of the accidents with oil tankers *Erika* and *Prestige*, in order to develop and implement EU legislation on maritime safety, pollution and security (EMSA, 2009).

The flag states

Every state has the right to register ships. The country where the vessel is registered is called the flag state and with registration follows that both owner and vessel must comply with that nation's legislation. National registers are often open for any owner fulfilling the requirements but do not distinguish shipping from other business in the country. Open registers on the other hand are principally designed to attract shipowners with favourable fiscal and legal terms regarding taxes, crewing, company law and safety standards. This liberty of choice has led to economical strategic decisions on ship registration. Shipowners can decide to fly a so called Flag of Convenience depending on how requirements and economic terms offered by the various registers suit the owner, vessel and its trade. In 2011, more than 68 per cent of the world's tonnage was registered under a foreign flag (UNCTAD, 2011) with the three largest flags of registration being Panama (21.9 per cent of the world fleet), Liberia (11.9 per cent) and the Marshall Islands (7.1 per cent). But also such disparate nations as the landlocked Mongolia and the small island nation of Kiribati, with a land area half the size of greater London, offer ship registers.

The International Maritime Organization (IMO)

The International Maritime Organization (IMO) is the UN agency attending to maritime matters. The IMO and its 170 members and three associate members, have adopted more than 800 conventions, codes and recommendations concerning maritime safety, prevention of pollution and related affairs (IMO, 2012). A historical retrospect reveals that fundamental regulatory changes have come in the aftermath of maritime disasters. The sinking of the *Titanic* initiated the international Convention for the Safety of Lives at Sea (SOLAS), today still regarded as the most important treaty (Veiga, 2002). SOLAS specifies how ships shall be constructed to be as safe as possible and covers all aspects, from stability and fire protection to the carriage of dangerous goods and port security.

In 1967, the 120 000-tonne crude oil tanker *Torrey Canyon* that ran aground off the Isles of Scilly originated the MARPOL convention of 1973 to tackle operational and accidental pollution, as well as the Civil Liability Convention concerning the compensation of victims of oil spill damage after an accident at sea (O'Neil, 2003). IMO also established the Marine Environment Protection Committee (MEPC) handling environmental issues. In the wake of the capsizing of the ro-ro ferry *Herald of Free Enterprise* off Zeebrugge in 1987, IMO adopted the International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code) that became mandatory in 1998 (Goulielmos and Goulielmos, 2005). The objective was to ensure safety, to prevent human injury or loss of life, and to avoid damage to the environment. The ISM Code requires the implementation of a safety management system (SMS) on all ships over 300 gross tonnes. Ship operators must develop policies and procedures for a systematic and self-regulating management of occupational health and safety matters (IMO, 2010).

In 1978, IMO adopted the international Convention on Standards of Training, Certification and Watchkeeping (STCW), establishing basic requirements for seafarers on an international level. Primarily, the flag state is responsible for examining and certifying the seafarers serving on vessels flying its flag, and this is then supplemented by port state control in the coastal states (Marten, 2011). Previously the standards of training, certification and watchkeeping of seafarers were established by individual governments, usually without reference to practices in other countries and could thus vary widely. Some areas of expertise require a special certificate and may require regular updates of knowledge and skills through training courses (IMO, 2011). For areas not specifically covered in STCW, knowledge development and training is left to company policy and structures for individual and organizational knowledge development and transfer.

The STCW convention has since undergone two major revisions, in 1995 and most recently trough the Manila amendments that entered into force on 1 January 2012. Important changes to the convention mirror the technological development in the industry and include, for instance (IMO, 2011):

- Revised requirements on hours of work and rest and new requirements for the prevention of drug and alcohol abuse, as well as updated standards relating to medical fitness standards for seafarers

- New requirements relating to training in modern technology such as electronic charts and information systems

- New requirements for marine environment awareness training and training in leadership and teamwork

- New requirements for security training, as well as provisions to ensure that seafarers are properly trained to cope if their ship comes under attack by pirates

- Introduction of modern training methodology including distance learning and web-based learning

- New training guidance for personnel serving on board ships operating in polar waters; and for personnel operating Dynamic Positioning Systems

The International Labour Organization (ILO)

The UN agency International Labour Organization (ILO) influences the occupational health and safety issues in the industry. Since the start in 1919 the organization has adopted more than 65 international labour standards related to seafarers. In 2006, ILO adopted the comprehensive Maritime Labour Convention (MLC) sometimes described as the 'fourth pillar' of the international maritime regulatory regime. This new 'super convention' aims to achieve both social and labour rights for seafarers as well as fair competition (level playing field) for shipowners (McConnell, 2011). The convention entails an update and consolidation of earlier ILO conventions and recommendations, addressing conditions of employment, accommodation, recreational facilities, food, health and social security protection (ILO, 2006). When globally applicable and uniformly enforced in 2013, Port State Control Officers will be empowered to detain ships showing major non-compliance with the convention.

3 RESEARCH APPROACH

This chapter describes the researcher's journey, introducing the overall research approach and describing the methods for data collection and analysis.

3.1 An exploratory qualitative research approach

The aim of the research work presented in this thesis is to develop a value proposition of maritime ergonomics from individual, organizational and societal perspectives. With such a broad scope, a qualitative, exploratory research approach was considered appropriate in order to capture rich, detailed information on the nature of maritime ergonomics and its potential value. A qualitative, exploratory research focuses on meanings rather than quantities (Denzin and Lincoln, 2008) and allows discovery of concepts not yet known during the investigation (Merkens, 2004).

In order to gain in-depth understanding, a triangulation approach was adopted within and across the studies. Appropriately, the triangulation metaphor is commonly related to the art of navigation strategy, where it refers to the use of multiple reference points to locate an exact position. In research practice, four types of triangulation can be outlined (Bryman and Bell, 2007):

1. Data triangulation including time, space and person to ascertain a variety of conditions,

2. investigator triangulation involving more than one investigator in the research process,

3. theory triangulation in regards to the application of theoretical perspectives, and

4. methodological triangulation, possibly the most discussed type of triangulation, referring to the use of multiple methods when examining a social phenomenon.

The research work is based on an overall triangulation of perspectives across studies to provide different images of understanding: from the macro perspective, studying the maritime transport system as a whole, to a micro perspective, studying one single technical system on board a vessel. Within the studies, methodological triangulation has been employed through the use of different methods for data collection and analysis.

Research is not a goal but a means for the advancement of knowledge. This knowledge will however always be the result of a number of selection processes where the researcher takes sides through his or her choices of research paradigm, methodology and study objects. In qualitative research, it is appropriate to account for the researchers pre-understandings when entering the research work. A researchers pre-understanding such as experience, knowledge and insights into a particular problem area or setting can influence the choice of research approach and methods and implies a certain attitude and commitment on the part of the researcher (Gummesson, 2000). Relevant experiences, beliefs and values that has shaped the author of this thesis emanates from academic studies in maritime engineering, work environment management and ergonomics. Important prior work experiences include working more than ten years at sea in the engine department, a position as shipyard safety engineer, and as inspector at the Swedish Work Environment Authority. Influential theoretical perspectives and previous research are accounted for in chapter 2, Frame of reference.

The research activities consist of the seven studies (reported in Paper I–VI) and a cross-study analysis and synthesis of the research as a whole. The analysis and synthesis aims at connecting the individual studies and the thesis' objective – in other words, tying the knot between ergonomics and systems performance in shipping.

3.2 Data collection methods

Methods for data collection in qualitative research are primarily concerned with the gathering of information in the form of words, rather than figures (Jacobsen, 2002). The data collection methods used in the research presented in this thesis include literature studies, semi-structured qualitative interviews, focus group interviews, structured interviews, and a case study.

3.2.1 Literature review

All conducted studies involved literature studies. Paper II and IV were however specifically initiated and designed as literature reviews. A literature review constitutes the foundation of knowledge necessary for the different phases in a research project (Williamson, 2002) and is a part of the academic development in understanding the topic and identifying previous research and key issues (Hart, 1998). For the present thesis, search for relevant scientific literature has been made continuously. A snowball strategy was adopted, where bibliographies and references of the retrieved, relevant studies were followed up and reviewed. Analysis was performed by the literature being read, re-read, summarised and tabulated. Key ideas, concepts, problems, theories and interpretations were systematically extracted.

All sources used in the present thesis work are original sources and the bibliographic software EndNote has been used for organizing and managing bibliographies and references.

3.2.2 Individual interviews

Individual interviews were performed in the studies reported in Paper I, III, and VII. Interviews are frequently used for data collection in qualitative research in order to gather comprehensive accounts of attitudes, views, and knowledge regarding a given topic. Kvale (1997) describes the qualitative research interview as a conversation with a structure and a purpose, aiming for insights and new understandings. Two metaphors illustrate the different ways of viewing knowledge created through a research interview: the researcher as a miner or as a traveller. The miner is digging up nuggets of data, while the traveller creates knowledge during the voyage. The knowledge process in an interview is an interactive process between interviewer and interviewee. Hence, it is important to check continuously that the interpretation of the said is accepted by the informant.

In a semi-structured interview (used specifically for Paper I and VII), the researcher uses a thematic guide as framework, allowing for flexibility to probe for details or further discuss issues (Williamson, 2002). Since the questions follow the flow of the informant rather than being asked in the order of the guide, it is important that the interviewer is flexible and sensitive to the informant. By using semi-structured interviews, it is feasible to compare the answers from several interviews and, to a certain extent, make some generalisations.

3.2.3 Structured interviews

Structured interviews were performed in the study reported in Paper I. Here, the structure of questions, attendant questions, sequence and interview situation is designed in advance (Williamson, 2002). The informant is asked about one or more problem areas and little room is left for discussion or probing for details. The results of several structured interviews are generally easy to evaluate and compare across the informants.

3.2.4 Focus group interviews

Focus group interviews were performed in the studies reported in Paper VI and VII. Focus group interviews are usually characterised by five elements: they involve (1) a group of people, composed of (2) participants with certain features important to the researcher, that (3) solicits qualitative data in a (4) carefully planned focused discussion, in order to (5) gain understanding of the chosen topic through the eyes of the target audience (Krueger and Casey, 2009).

The group dynamics and interaction that occur in focus group interviews are a vital part of the method, using the communication between research participants to generate data. Instead of a researcher asking individuals to respond to a series of questions in turn, the participants are encouraged to, in their own vocabulary, ask each other questions, narrate anecdotes and comment on each other's experiences and points of view (Krueger and Casey, 2009). Focus group interviews are particularly useful for exploring participants' knowledge and experiences, probing not only what people think but how they think and why they think that way (Kitzinger, 1995).

3.3 Data analysis and synthesis

The terms analysis and synthesis originates from ancient Greek and translates literally to unloose and put together respectively (2006). Generally, analysis can be defined as the process by which an intellectual or substantial whole is divided into parts or components (Ritchey, 1991). In qualitative research, the dividing line between data collection and data analysis can be vague and there are few well-established and generally accepted rules for analysis (Bryman and Bell, 2007). The analytic process starts during the data collection phase and occurs continuously in a dynamic interplay with the data collection. Rather than being a distinct activity, the data analysis shapes the next phase of data collection by developing new routes of inquiry and refining questions (Krueger and Casey, 2009). Every analysis requires a subsequent and complementing synthesis in order to verify and correct its results Synthesis is generally defined as the opposite process to analysis and signifies a combination of the separate elements or components in order to form a coherent whole (Ritchey, 1991).

The present thesis work is based on information acquired from verbal and non-verbal dialogues and texts by means of written and spoken words as well as body language during interviews. The gained understanding from each research activity has been reflected upon moving between multiple levels of abstraction during the research process. Vicente's (2004) Human-Tech ladder has been used as a ladder of abstraction, a technique for thinking explicitly about the various levels. Each individual study has contributed in the search for an understanding of the overall principle on how the parts interplay. The performed analysis and interpretation of data can be described as a process to bring structure, order and meaning to the data, in short – making sense of the data. The techniques for analysing the data have varied with the methods, theoretical positions or topic areas in the individual studies. However, in accordance with the process described by Jacobsen (2002) three elements in the process of analysis and synthesis remain central for all work in this thesis:

1. Detailed description of the data. In order to get to know the data, tape recordings have been listened to several times and transcripts and notes have been read and re-read while writing down impressions and thoughts.

2. Systematisation, reduction and categorisation of the data. This was organized around the questions or topics in the studies in order to identify consistencies and differences in the material, and looking for emerging themes, patterns, interactions or terminology that recur in the data. The data was organized into summarizing categories in an iterative process, labelling and re-labelling the categories until no new themes could be identified.

3. Linking and connecting of data to look for meanings and causes. Here, the data was interpreted and synthesised, looking for relationships in the data and attaching meanings to the analysis. The move from analysis to synthesis was an iterative process moving towards a creation of entirety and ultimately the fulfilment of the research aim; identifying the core values of maritime ergonomics.

4 RESULTS

This chapter summarises procedures and key findings from the seven studies in Table 1.

4.1 Paper I – Exploring maritime ergonomics from a bottom line perspective

The aim of this exploratory, qualitative study was to investigate:

- if any previous studies on the costs and benefits of ergonomic work have been carried out within the shipping industry,
- if the models and methods developed within other domains can be applied in shipping,
- if Swedish shipowners calculate the economic effects of the work environment,
- which key ergonomic factors that have been addressed in previous maritime ergonomic research, and
- which ergonomic factors that are considered most important by practitioners in the Swedish shipping industry.

4.1.1 Procedures

The study was composed by three main research activities: a literature review, nine semi-structured qualitative interviews on maritime ergonomic factors, and structured interviews with representatives from ten Swedish shipping companies on the calculation of economic effects of ergonomics.

4.1.2 Key findings

The literature review found a number of methods developed for evaluating the economics of ergonomics developed for other industries, but no studies that investigated the economics of ergonomics within the maritime domain. Since most of the methods emanated from typical production environments, the benefits were often expressed in terms of increased productivity, efficiency and quality. For these operative measurements to be readily applicable in the shipping industry, it is necessary to first define what these concepts mean in a maritime context.

The results of the structured interviews with the ten Swedish HR managers showed that the sick-leave costs were known by all informants in the study. But, only two informants stated that they regularly perform any other cost and benefit estimates of ergonomics.

In the paper it was cocluded that for the past ten years, maritime ergonomics research has focused primarily on issues regarding physical ergonomics and occupational health rather than a broad perspective of ergonomics. The practitioner's perspective, on the other hand, revealed a predominant focus on organizational ergonomics. The ergonomics issues brought up by the informants during the semi-structured interviews as being the most important could be categorized into six factors: leadership, knowledge, culture and values, human resource management, communication, and employee participation. In addition, all informants also expressed concern on how the global shortage of competent seafarers, especially officers, affects the safe operation of ships.

4.2 Paper II – The human element in maritime logistics

This study continues where Paper I ended, addressing overall system performance and wellbeing in a maritime context and investigating how productivity, efficiency and quality in shipping can be operationalized, measured and linked to ergonomics.

4.2.1 Procedures

A literature review was performed in order to define and delineate the concepts of productivity, efficiency and quality as determinants of operational performance in a shipping company, which could be related to maritime ergonomics. Search for relevant literature was primarily conducted in the academic databases Business Source Premier, Science Direct and Scopus. The following search criteria were used, truncated and in different combinations: shipping, maritime, productivity, effectiveness, efficiency and quality. The inclusion criteria were formulated as: scientific literature, written in English or any of the Scandinavian languages, reporting on studies from the maritime industry where productivity, efficiency or quality was defined. Studies concerning port operations only were excluded. A snowball strategy was adopted where the bibliographies of the retrieved, relevant studies were followed up and reviewed. The search for relevant literature was iterated until the data corpus was considered sufficient.

4.2.2 Key findings

The literature review revealed various definitions of productivity, efficiency and quality in shipping. However, cargo and crew emerged as central elements in all three concepts and it is suggested that the productive time at sea, as well as efficiency and quality of operations, can be increased by means of proper design of both technical and organization systems.

In the paper, a conceptual framework is described, illustrating how increased knowledge of ergonomic principles can contribute to increased productivity, operational efficiency, service quality, and operator well-being in the maritime domain. The framework shows that productive time at sea can be improved by addressing ergonomic factors that contribute to a minimum of unproductive days due to maritime and occupational accidents, operational disturbances of machinery and equipment, time consuming inspections and potential subsequent detentions, or loss of business opportunities. Operational efficiency can be improved by addressing the organizational ergonomic factors that contribute to crew efficiency, such as organizational and managerial structures, communication, design of working times, and knowledge creating processes. Technically, operational efficiency would benefit from a ship design that allows for more than just operability, and also takes into account the ship's maintainability, working conditions, habitability and survivability for a safe and efficient ship operation over time. Maritime service quality can largely be equated with safety. It is likely that the self-regulating quality management systems in place today, especially within the liquid bulk segment, will continue to develop within other shipping markets. Moreover, that the public awareness and pressure on shipping to deal with environmental issues will expand to encompass social and ethical issues such as fair working conditions.

In conclusion, the outcome of a systematic ergonomics management was found to be assessable in terms of individual, organizational and societal benefits. As illustrated in the compilation of factors in Table 4, examples of individual benefits include reduced risk for occupational accidents, improved physical and mental health, and job satisfaction. Organizational benefits include improved productivity, efficiency and quality, reduced risk for liabilities, and improved human resource management regarding recruiting and retaining, absenteeism and labour turnover.

Table 4 *Factors affected by ergonomics on individual, organizational and societal level*

Level	Factors affected by ergonomics management
Individual	Occupational accidents, health, job satisfaction
Organizational	Productivity, efficiency, quality, liabilities, human resource management
Societal	Costs for accidents and ill-health, sustainable transports and working life

On a societal level, benefits include reduced costs for ill-health and accidents, and in a larger perspective a contribution towards an economically, environmentally and socially sustainable maritime transport system and society as a whole.

4.3 Paper III – Assessing financial impact of maritime ergonomics on company level: a case study

In this study, the theoretical reasoning and the metrics concerning the financial impact of ergonomics on company level suggested in Paper II were studied in the setting of a Swedish shipping company. The aim of the study was to investigate:

- availability and applicability of the suggested determinants for productivity, efficiency and quality in a shipping company's maritime operations,
- routines for performing cost and effect estimates of any ergonomics interventions or investments, as well as for accidents, operational disturbances and inspections, and
- customer interest or demands for ergonomics.

4.3.1 Procedures

A single, exploratory case study was performed using a Swedish shipping company with a diversified fleet as case. The company was chosen for the case study on basis of the company´s perceived suitability in representing a typical Swedish shipping company, as well as being accessible for research. Data for the shipping company and six vessels were collected for the years 2008 to 2010. Based on the methodology described by Yin (2009), the documentation was examined, categorised, recombined and tabulated in a case study database with focus on information relating to the operational performance determinants suggested in Paper II. At company level, the documentation included policies, financial statements, procedures, circulars and work instructions. For each vessel, documentation was collected regarding personnel and employment data, non-conformities, accidents and incidents, inspection and audit reports, and other operational data.

The systems approach for this case study involved contacts with a multitude of functions and persons on different levels in the company. During the search and retrieval for relevant data and documentation, open-ended interviews were held with company managers and assistants in the departments of Safety & Security, Finance and Operations.

4.3.2 Key findings

The results show that the framing concepts of productivity, efficiency and quality adopted from the production industry paradigm were not semantically appropriate. In the setting of this case study, these concepts were largely undefined and not used in daily language within the Company. Especially the concept of productivity proved difficult to apply. The sub-categories and suggested determinants for productivity, efficiency and quality were however found to be present and applicable, albeit not actually measured to any large extent. The Company was found to have a strong commitment to safety and environment work, but did not use any specific method or model to estimate costs or benefits of this effort.

The company has a meticulous data base for personnel matters, such as data for employment, qualifications, sick-leave and competence. The data was however not linked to production factors, except for the direct costs for sick-leave, nor was the data regularly used as basis for cost estimates in order to evaluate investments or interventions. Even so, when discussing some of the investments made to improve health and safety on board with the informants, it was generally believed that the investments were 'profitable'.

Although some of the database entries would allow for cost estimates, this function was rarely employed. The database for accidents and incidents has a scroll down menu for cost estimates and this was occasionally completed, but rarely followed up. The entry for recruitment costs included in the Ship Operating Costs Report where however not completed for any of the six vessels during the investigated three years period, despite the employment data showing personnel turnover on all six vessels during this period. In the paper, it was concluded that the act of measuring in itself will not improve health and safety on board. But increased knowledge about the actual costs and effects of ergonomics on operations can contribute to corporate strategy and the management's ability to make informed decisions.

Further, the results of the case study show an expressed interest displayed by the customers of the shipping company for environmental and increasingly also social and ethical matters regarding the maritime transport service. Several of the customers have their own Corporate Social Responsibility standard that must be met in order to obtain a contract. In addition, since all six vessels included in the study operate in waters with specific regional legal environmental requirements competence, there are societal demands and expectations on the company that imply rigor in routines for maritime safety and crew.

4.4 Paper IV – Performance influencing factors in maritime operations

This paper presents an analytical review of important performance influencing factors (PIF) relevant for maritime operations.

4.4.1 Procedures

This analysis is based on the taxonomy for performance influencing factors developed by Kim and Jung (2003), that in full consists of 220 detailed factors classified into four main groups: human, task, technical system and environment.

The selection of subgroups and detailed items for further analysis is based on the results presented in Paper I.

4.4.2 Key findings

The performance influencing factors included in the analysis are summarised in Table 5.

Important individual physical and psychological characteristics known to influence **human** performance of both daily activities and emergency operations at sea are physical and mental health issues, fatigue, stress, and alcohol and drug abuse.

The many **tasks** and procedures performed on a vessel during normal and emergency operations vary greatly in complexity and physical load. The increased development and implementation of complex shipboard technology has brought new cognitive and mental demands for the operating crew on board. Instead of manually executing tasks, the role of the crew has moved towards primarily sedentary work such as supervisory control, monitoring, and fault-finding. There are, however, still many physically demanding manual handling tasks on board.

The state of a **technical system** depends on its inherent complexity, reliability, redundancy and level of automation. Further characteristics include for instance human–machine interaction and design, mapping and reachability of indicators, controllers and panels. Poor interaction with technological systems has contributed to several marine accidents. Similarly, overreliance on technical systems can lead to less effective monitoring.

Environmental characteristics include physical working conditions and organizational factors. Vessels are generally built to ensure optimum cargo carrying capacity, keeping space requirements for other functions to a minimum. The work environment on board still causes a high level of occupational accidents. Important design aspects known to affect work and safety performance include, but are not limited to, noise and acoustics, lighting, thermal climate, air quality and ventilation. Poor design can also expose an operator to unnecessary physical workloads and uncomfortable work movements.

Table 5 *Performance influencing factors relevant for maritime operations*

Main group	Subgroup	Detailed items
Human	Physical and psychological characteristics	• Physical and mental health • Fatigue • Stress • Alcohol and drug abuse
Task	Procedures	• Availability • Quality
	Task characteristics	• Task type • Task requirements
System	System state	• Complexity • Reliability • Level of automation
	Human–machine interface	• Indicators / controllers • Panel / screen layout
Environment	Physical working conditions	• Workplace design • Physical work environment factors
	Organizational factors	• Management and policy • Team-related factors • Training

Organizational performance influencing factors were found at industry, company and vessel level. The industry level, encompassing the entire maritime system, essentially directs how ships are designed, built and operated through a number of rules and policies that influence the overall system performance of maritime operations. On company level, vessel operation performance is influenced by management policies, norms and values. Crewing, including manning levels, crew composition, routines for crew change and training, is an important issue and a major part of a vessel's operational costs. Crew handover plays an important part in the understanding of new equipment and socialising into the group.

By way of conclusion, when viewing the abovementioned factors as risk factors, potential outcomes of impaired performance include maritime and occupational accidents, reduced productivity, efficiency and quality of operations. But, these factors can also be treated as success factors that, properly managed, can contribute to increased overall system performance and human well-being. Technical and organizational solutions need to be identified, located and supported within transparent structures that demonstrate management commitment and good communication between all stakeholders: legislators, insurers, classification societies, shipbuilders and manufacturers of technical systems, shipyards, owners and seafarers.

4.5 Paper V – Developing a training course for systematic review of ship drawings from a work environment perspective

The aim of this paper was to develop and test a training course for seafarer safety delegates for systematic review of technical ship drawings from a work environment perspective, suitable for learners with little or no previous experience.

4.5.1 Procedures

The research approach in this course development project was inspired by the iterative participatory action research framework (McTaggart, 1991, McTaggart, 1994) and problem-based learning methods (see, for instance Albanese and Mitchell, 1993, Savery and Duffy, 1996). The process includes continuous steps of planning, action, observation and reflection in order to bring about improvement and generate knowledge (Oosthuizen, 2002).

In all, observations were made during three separate training sessions utilising input and collected experiences from in all 70 participating seafarers. Table 6 shows the number of participants at each training session, gender distribution and the number of shipping companies that were represented.

***Table 6** Summary of training sessions and participants*

Training session	Date	Participants	Shipping companies
1	February 2010	24 (15 men, 9 women)	10
2	November 2010	25 (13 men, 12 women)	9
3	February 2012	21 (13 men, 8 women)	8

After each training session the participants were asked to answer a written course evaluation. The results of the course evaluations were used as input in the course development process. However, since the first and the following two course evaluations differed from each other, they could not be used for direct comparisons.

4.5.2 Key findings

The results of the project show that it was possible to involve seafarer safety delegates in a ship design process regardless of their limited command of technical drawings. Naturally, there are many functional, technical and legal aspects in a ship building process that fall beyond the scope of this project. But, through a combination of principles for learning and established ergonomics methods, the safety delegates could add valuable input to an otherwise rule-based ship design process. With their knowledge of tasks and processes at the workplace, the safety delegates balanced the prevalent technical detail perspective with a strong focus on functionality. Such an approach would lead to more effective and well thought out design solutions and could ultimately contribute towards safe, efficient and sustainable operation of ships.

The outcomes of the learning activities can also be discussed in terms of empowering the safety delegates and inspiring confidence to embark on real design projects in the future. The course is further a possibility for the learners to network, exchange experiences and discuss mutual challenges in their role as safety delegates and as professionals.

Further, the results of this course development project maintain pedagogical theories regarding the importance of problem-based learning, as a means of motivation as well as facilitating a deeper understanding of a complex topic. Teaching is improved by a more systematic approach to the topic, which however requires more preparations. Learning is improved by leaving the prescriptive approach and use a more function-oriented and collaborative method with tasks and scenarios familiar to the learners (Knowles et al., 2005).

4.6 Paper VI – Enabling end-user participation in ship design

This study investigates the possibility to include seafarers in a participative ship design process in a cost-efficient manner, and further to investigate whether simple representations of a ship bridge can generate valuable information. Specifically, the study seeks to answer the following questions:

1. What kinds of comments from end-users can be elicited using simple 3D representations?

2. What kind of input towards the design process can such 3D-mediated discussions contribute?

4.6.1 Procedures

Six groups of three participants in each group were recruited among nautical cadets in their third or fourth year at a Swedish merchant marine academy. The participants were asked to evaluate four different representations of a ship bridge, with respect to work environment and workplace efficiency. The ship bridge was first presented on a 2D paper drawing followed by three different 3D models in altered succession; a 3D drawing in a CAD program with a mannequin function, a 1:16 paperboard model, and as a 1:1 plywood mock-up. A use scenario workshop (Broberg et al., 2011) featured three different scenarios for the bridge work. A written questionnaire was used to elicit specific input about the models in which the cadets were asked to give feedback on the scenarios for each of the four representations, first individually and then discuss within the group.

4.6.2 Key findings

Despite their relatively limited work experience, the participating cadets were able to give useful comments transferrable to valuable input in a ship design process. All representations received comments from all participants, which can be seen as an acceptance of the models as boundary objects. At large, the written individual comments and the following group discussions referred to issues important for safe and efficient ship operations. It was also noted that the participants were able to relate past seafaring experiences to the suggested design related to specific use situations.

The 3D representations were considered most helpful for envisioning the workplace design and enabling user participation. Specifically, the participants appreciated the possibility to be able to walk in the 1:1 mock-up, using their own bodies as a size reference when evaluating the ship bridge design.

With no prompts apart from the described scenarios, the participants were able to give detailed feedback about how different layout details would affect their ability to work in the proposed layout. Many of the participants' comments covered design aspects that a design team would benefit from taking into account, but that would be difficult to ascertain without first-hand user experience. These comments regard movement patterns, priorities in workflow, multiple uses of the same workspace or surface, vision-related requirements, comfort concerns, and behaviours related both to work and leisure, recognising the ship as a social as well as a working environment.

Without being prompted, the participants also considered economic aspects when evaluating the models' use for a real ship design process. Several comments concerned the costs and resources for making and modifying the different models.

In conclusion, the results show that the evaluation methods and representations used in the study would be useful in a real ship design process and probably even more so with experienced seafarers participating. With relatively small means, the procedure supports the benefits of employee participation, contributing to a safe and efficient ship design and subsequent operation.

4.7 Paper VII – A systemic review of shipboard SCR installations in practice

This paper explores the human–machine aspects of installations of selective catalytic reduction (SCR) catalysts from a systems perspective. The aim was to identify important technical, human and organizational conditions necessary for safe, efficient and sustainable SCR operations. In addition, the study set out to investigate to what extent the capabilities and limitations of human operators and maintainers have been taken into account in the design and installation phase of the SCR systems thus far.

4.7.1 Procedures

A combination of focus group interviews and individual interviews was used. Two focus group interviews (n=10) were held with top or middle managers recruited on basis of their anticipated first-hand knowledge and experiences of SCR catalysts. Both focus groups followed the same semi-structured interview guide with predominantly open-ended questions about SCR installations on the three themes of:

1. Installation: newbuilding and retrofit, decision making, stakeholder communication

2. Operation, service and maintenance: usability, accessibility, manuals, support, outage, costs.

3. Knowledge and training: before and after installation, knowledge transfer

The focus groups concluded with the participants anonymously answering a structured questionnaire to assess if the group discussions had succeeded in capturing the most important practical experiences on the three themes respectively, whether the participants felt that they had had the opportunity to express their opinion, and the potential usefulness of the discussions to the participants. In addition, five individual, semi-structured interviews were held, using the same thematic interview guide as the focus group interviews. The informants were chosen among specific stakeholders with experiences considered relevant by the researchers.

4.7.2 Key findings

The results of the study show that although the NO_X reduction with marine SCR catalysts is large in successful installations, there are still technical and operational issues that need to be resolved for forthcoming SCR installations. Principally regarding the supply and quality of urea, the design and placing of urea-injection, and exhaust gas composition due to various marine fuels and lubrication oils.

The results indicate that there are currently no structures or procedures in place to ensure that physical and cognitive capabilities and limitations of the human operators and maintainers are taken into account in the design process. Also lacking is a structure for training and the development and transfer of knowledge of how the SCR works and how to properly operate and maintain the SCR. This absence of structures and procedures is a contributing source to the common operational disturbances, increased maintenance needs, increased risk for occupational accidents, and reduced catalytic efficiency (less reduction of harmful air emissions to the environment). The costs associated with these problems are carried by shipowners, cargo owners and the society.

Early marine SCR installations were found to be poorly adapted for the prevailing conditions on board, for instance in respect to vibrations, exhaust gas composition and soot due to the different oil types that are commonly used for ship engines. Later installations were believed by the informants to be better adapted in this respect. The narratives during the interviews included many portrayals of things falling apart, clogged catalytic stones and ineffective NO_X reduction. Several cases of more or less conscious sub-optimisations of SCR installations could be attributed to a combination of the limited space available for installations on board, and a lack of understanding by system builders and operators of core chemical processes in the SCR.

In conclusion, the results of the study show that the use of established ergonomics principles and methods in the design and installation process of marine SCR systems, and possibly other forthcoming abatement technologies, could improve the overall system performance. It would also contribute towards reaching future environmental targets regarding NO_X emissions from shipping. Further, it was concluded that the face-to-face focus group meetings had a positive impact on the dialogue and knowledge transfer between the shipowners and the SCR manufacturers.


UNITOR

5 ANALYSIS ACROSS STUDIES

This chapter presents a cross-study analysis of the results in the seven studies structured around the three research topics. It is followed by a section on the application of ergonomics management in the maritime transport system. The chapter is concluded with a synthesis of the results in relation to the thesis aim, tying the knot between good ergonomics and good economics in the development of a value proposition of maritime ergonomics.

5.1 Key issues in maritime ergonomics

Paper I investigated the key issues in maritime ergonomics from two perspectives. The theoretical perspective turned to the scientific literature to examine which major issues that have been addressed in previous research. The practical perspective turned to the industry to examine if the economics of ergonomics was known in the industry and which ergonomic issues were considered important. The review of literature on maritime ergonomics indicated a focus on physical ergonomic and occupational health issues from a medicinal perspective. An explanation to the emphasis on physical ergonomics is undoubtedly that seafaring still is a hazardous occupation with a high incidence of accidents and illnesses compared to many other industries (Ellis et al., 2011).

Few studies report on organizational and psychosocial ergonomic factors, indicating that the systems view of humans at work is scarce in maritime ergonomics research. However, a reason for the limited number of studies can be the practical difficulties in designing and carrying out studies on the maritime domain. Especially to arrange visits to the ships and meet the people working on board in their daily working situation and not only meet the shore based part of the organization. Field studies might be difficult to plan since ship schedules are known to change with short notice, and are further complicated by the restricted possibility for a ship to accommodate visitors due to a limited number of cabins on board.

Moreover, the literature shows a strong focus on the work performed in the deck and engine department while the catering department is largely invisible. Although the daily work of the catering personnel might not be perceived as immediately safety critical, it naturally affects customer satisfaction. Further, as demonstrated for instance in the sinking of the *Costa Concordia*, the catering crew plays a vital role in emergency situations where they are often responsible for the safe evacuation of passengers in case of fire or abandoning of ship.

The ergonomic factors that emerged from the interviews were all organizational issues: leadership, knowledge, culture and values, human resource management, communication, and employee participation. Well managed, the informants consider these issues to yield fewer marine accidents, personal injuries and damaged equipment, or as an informant put it: *'fewer surprises'*. A motivated, skilled crew is thought t o do a better job operating and maintaining the vessel, and if an accident occurs, to be better prepared for mitigation; thus limiting costs and time off-hire. In a longer perspective, a well maintained ship benefits in less costly mandatory periodical surveys and a better price on the second-hand market.

Several of the informants use the expression 'fire fighting' when describing safety and ergonomics work, that priority is given to the most necessary tasks as they appear and that there is not sufficient time for proactive work. There is however a risk that solely being able to respond to what happens, being limited to reactive behaviour, will ultimately lead an organization to lose control.

Notably, two informants representing different marine insurers both maintained that the 'visible owners', who have a close relationship with the crew and are successful in communicating policies and targets, have fewer insurance claims. This statement corresponds well to conditions known to influence performance of an organization, and when and how an organization loses control. These conditions include defective leadership leading to unattainable demands, inadequate or overoptimistic planning, or a lack of foresight; lack of knowledge and competence; and lack of resources (Hollnagel and Woods, 2005).

Manning of ships is a pivotal element in the shipping industry, a topic that was also touched upon by all informants in the study. Regularly, surveys from various organizations are published which analyse the global supply of seafarers and the demand from the expanding fleet. Although the gap between the demand for seafarers and their availability has narrowed in the wake of the recent financial crisis, appropriately qualified seafarers are still high in demand (Drewry, 2012). Rather than shortage in number, the weak point seems to be the absence of competent seafarers, with good command of English and communication skills (Xhelilaj et al., 2012). A major concern is the future availability of senior management level officers, engineers and seafarers in specialist segments of shipping which normally require a higher level of competence (BIMCO/ISF, 2010). Recently, joint efforts have been made to recruit new people to the shipping industry (for example the Go to Sea! campaign launched by IMO in association with a number of shipping NGOs).

Moreover, it is just as important that people remain within the industry. Seafaring is no longer a lifetime employment, but rather a stepping stone for a future career ashore. Many organizations such as marine insurers, classification societies and maritime administrations regularly employ people with seagoing experience. These people bring not only factual, but vital contextual knowledge and skills of maritime operations and the work on board. Hence, it is fair to assume that it will be increasingly important to adequately address ergonomics factors that contribute to attractive workplaces to which people want to apply for a job and where they want to stay. In a model developed by Hedlund (2007), attractive work is described as a dynamic function of three dimensions: attractive working conditions, work content and work satisfaction. The three dimensions are closely linked to physical, cognitive and organizational ergonomics factors regarding the physical work environment, working hours, social relations, leadership, variation in work content and stimulation (Hedlund, 2007).

In summary, it seems that research on the maritime domain so far has had predominant focus on physical ergonomics and safety factors, rather than organizational factors, which the informants in this study were more concerned about. A shift towards a more holistic approach in future research, covering all dimensions of ergonomics (physical, cognitive and organizational) and encompassing all members of the crew should be appropriate to meet the needs of tomorrow's shipping industry.

5.2 Effects of ergonomics on operational performance

The study reported in Paper I identified a need for detailed modelling of maritime operational performance. Naturally, this is not possible to obtain in a single metric and it was suggested that the concepts of productivity, efficiency and quality be adopted from the production industry paradigm. These concepts and their relation to ergonomics was explored in the analytical reviews reported in Paper II and Paper IV, and further investigated in terms of availability and applicability in the setting of a real shipping company, reported in Paper III.

Three main productivity indicators were found to be under the control of the ship operator: (1) accidents or injuries, (2) operational disturbances of machinery and equipment, and (3) inspections and detentions.

Accidents and injuries have a disruptive effect on operations both at the time they occur and in the aftermath with investigations, repairs, replacement of personnel, training and familiarization of new personnel. According to the European Maritime Safety Agency (EMSA, 2011), both the number of ships involved in accidents and lives lost increased in 2010 following a decline during 2009, suggesting a link between accident numbers and economic activity. During 2010, 644 vessels were involved in 559 accidents, and 61 seafarers lost their lives on ships operating in and around EU waters. The high occurrence of occupational injuries compared to other industries and the high costs for incidents involving crew members suffering from mental ill-health (NEPIA, 2006) implicate a high potential for improvements in this area.

Operational disturbances of machinery and equipment due to unplanned maintenance or breakdowns are costly in terms of direct costs for repairs, as well as for loss of productive time for ship, crew, and technical and administrative support ashore. Machinery damage and engine room problems remain the primary cause for serious losses, accounting for 35 per cent of all losses between 2006 and 2011 (IUMI, 2012). Returning to Vicente's ladder, alleged causes for these problems are found at the physical, psychological and organizational levels: the complexity of modern onboard systems that are not always fully understood, maintained or repaired, skill deficiencies among crew members, and neglect of technical inspection at management level.

This was illustrated in Paper VII, in which numerous anecdotes of things falling apart, clogged stones and ineffective NO_X reduction were reported. Many of the challenges in successfully operating an SCR system could be traced back to the design and installation phase. In what Reason (1990) called the blunt end of the SCR system (where managers, system architects, designers, and suppliers of technology are found), there appeared to be a lack of sufficient factual as well as contextual knowledge of technical and environmental prerequisites for a well-functioning system. This lack affects both the technical functionality (e.g. difficulties in maintaining suitable exhaust gas velocity and misplaced urea injectors) and maintainability. To continue Reasons analogy, in the sharp end (where the actual operation and maintenance takes place), the SCR is viewed by the operators largely as a 'black box' with no one to tell what actually happens inside. The restricted space for installation further implies that routine and repair work are performed with an increased risk for human errors and occupational accidents.

The SCR is but one example of a technical system on board, but the above described phenomenon can be seen in many other systems as well. Due to large costs and logistical challenges associated with the development of new systems for marine applications, the ship operators and their crew routinely take active part in this development, both technically and economically. When various prototypes and preproduction models are installed on board, the ship operators and crew also carry part of the development costs in terms of necessary re-engineering, material, working hours, energy and waste. In the case of the SCR, the latter was specifically seen in the overuse of urea and with catalyst stones not operating their full estimated service life.

Paper II and III investigated operational efficiency in shipping as a function of costs, time, and customer satisfaction. The results show that crew costs are a significant part of the operating costs. Generally, it is also seen as one of the most flexible costs (Leggate and McConville, 2002, Stopford, 2009), making strategies to improve individual and team performance high on any shipping company's agenda. Knowledge, skills and structures for communication are internal determinants of efficiency depending on managerial functions (Barthwal, 2000). As such, it is related to organizational ergonomics and the design of the socio-technical system, providing the work environment and prevailing conditions necessary for optimal crew performance.

As argued in Papers I and IV, on a political level the intrinsic manning structures in the global manning industry can be seen as a risk factor in itself and have a negative impact on the efficiency of operations at sea. On Swedish flagged ships it is common to have a more or less stable crew returning to the same position on the same vessel or at least within the same company for some period of time. In a global perspective, however, it is common for seafarers to have longer tours of duty on board than time off ashore. This leads to an inevitable turnover of crew and in turn an increased risk for accidents and operating errors. Contrary, stable crews returning to the same ship show reduced risk for accidents (Bailey, 2006, Carter, 2005, Hansen et al., 2002), findings that are consistent with research from other domains on temporary workers (Quinlan et al., 2001). A constant flow of new crew members also poses a psychosocial stressor on the individual in having to adapt to new colleagues on and off working hours on board. In addition, it can involve a perceived sense of inequality due to differences in wages, length of tours of duty, and employment benefits. In addition, as contended in Paper III, the crew turnover is also associated with substantial costs.

Considering the flexible nature of the maritime transport system, it is clear that a ship operating organization needs to be designed for resilience. It must be capable to adjust to internal and external events and stresses over time, and able to avert situations that can lead to potential disturbances of operations (Sundström and Hollnagel, 2006).

Quality systems in the maritime industry have emerged principally from regulation, such as the ISM code, rather than from a company-centric or product-based mindset (Bichou et al., 2007). As shown in Paper II and III, a ship is regularly subjected to inspections by various regulatory regimes and customers. Depending on executor, a failed inspection can result in the ship, or ship operator, being excluded for certain business opportunities, detention of ship, conditions or withdrawal of class, or a ban to enter certain ports or regions. In 2011, the Paris MoU reported deficiencies in 56 per cent of the inspections and 20 ships were banned from the region (Paris MoU, 2012a). A detained ship has significant cost implications for the shipowner in terms of loss of revenue and schedule disturbances, and because unplanned work undertaken at short notice is more expensive. Paris MoU regularly publishes a list of deficiencies and detentions along with photographs and particulars of ships in poor condition which have been 'caught in the net' (Paris MoU, 2012b). Thus, even if a ship is not delayed, a failed port state control reflects poorly on both vessel and its operator and can imply commercial consequences on customer relations and loss of future employment.

Over the years, several shipping sectors have initiated self-regulating vetting systems to enhance quality driven by commercial interests. This especially applies to the liquid bulk market due to the high media profile of tanker accidents and associated corporate image repercussions for any well-known brand involved. Notorious examples are the oil supermajors Exxon and Total. In the disastrous grounding of the supertanker Exxon Valdez in Alaska in 1989 the clean-up costs alone cost Exxon 2.2 billion USD (Merrick and van Dorp, 2006). Total, as the charterer of the oil tanker *Erika* that broke in two and sank off Brittany in 1999, was ruled by a French court in 2010 to pay 200 million EUR in compensation for damages (Fairplay, 2010). In order to promote safety and prevent pollution from tankers and at oil terminals, the Oil Companies International Marine Forum (OCIMF) produces many technical and operational guidelines that today are used as industry standards by ship operators to improve their safety management systems (OCIMF, 2004). Due to a perceived absence of economic incentives, similar market driven systems have been less prominent and have taken longer to develop within other segments (Tamvakis and Thanopoulou, 2000). But, as stated in Paper III, in recent years there has been an increased customer interest for safety and environmental issues also within the dry cargo market.

In summary, effects of ergonomics on operational performance are found at all interrelated system levels. In the sharp end, crew performance benefits from a decreased risk for occupational and maritime accidents, improved individual health and well-being and increased learning. At an organizational level, the effects on company performance are related to the productive time at sea in terms of accidents, operational disturbances and inspections, operational efficiency, and quality of the sea transport service. Several effects at company level ultimately spill over to the entire maritime sector, for example, costs for insurance claims are carried by all policyholders in a mutual insurance company. Less tangible are the effects of maritime accidents, pollutions and other high-profile events that influence the image and perception of the industry in the eyes of policy makers and the general public with consequences for competitive strength towards other modes of transport and recruiting of new personnel to the sector. At a societal level, immediate effects of occupational injuries and ill-health can be seen in costs for medical treatment, health care and social security. The SCR study also showed how the overall system design had effects on the environment through unnecessary air emissions.

5.3 Development and transfer of knowledge

Paper V, VI and VII were designed to investigate knowledge development and transfer within maritime ergonomics, and specifically crew participation when designing new workplaces or introducing new technical systems on board. During such a design process, there are many functional, technical and legal aspects regarding a ship's seaworthiness and operation to consider that demand special areas of expertise. Thus, the participatory approach and the inclusion of the crew as operators and maintainers of the working and living conditions on board is not a substitution, but a complementary resource to the multi-disciplinary design team.

The motivation for the studies described in Paper V and VI came from a realisation that despite the extensive tradition of employee participation in Swedish workplaces, and the longstanding legally prescribed rights and duties for safety delegates as employee representatives (SFS, 1912), seafarers seldom participate in workplace design and development projects on board. Among the reasons are the absence of an appointed crew (ships may even be built on speculation, although it is uncommon in the Swedish shipping industry), the different challenges of time and place that comes with the globalised nature of shipping and a perceived lack of value of crew participation to a design team. Crew participation is further complicated by the differences in professional background, command of technical drawings and the ability to communicate in engineering terms with a design team.

During the course development project described in Paper V, the course assignments matured into a systematic method that could serve as an investigative toolkit during a real design process. The method draws on theories and principles of participatory ergonomics and work task assessment techniques such as task analysis and link analysis (Stanton et al., 2005). This combination of established methods and principles for ergonomics, learning and participatory design enabled the safety delegates to take active part in a (fictional) ship design process, despite limited experiences of technical drawings. The group work presentations, as a symbol for a design proposal, had a strong focus on functionality and accommodated for actual tasks and processes in the workspace. They shaped their own use scenarios based on the tasks the participants believed to be most important and several of the groups also created mediating tools and low-fidelity mockups to enhance mental imagery, and especially a shared mental image within the group.

Notably, during all three course sessions, the deck group independently opted to analyse mooring operations on deck. This indicates a certain apprehension among the performers of one of the most hazardous tasks on a ship. Safety and ease of performance during mooring were thoroughly discussed from a holistic perspective, beyond the physical mooring equipment and its placing. Discussions included audio and visual communication between operators on deck, ashore and on the bridge, the various environmental conditions encountered during mooring and how to tackle frozen mooring ropes, among other things. The galley and shop groups all displayed a focus on flows and processes in their respective work areas. Transport of goods and customer throughputs were simulated by the participants in order to ensure effective operations and high service levels. Both examples serve as good illustrations of the kind of contextual knowledge and understanding that comes of practical experience. This knowledge is vital when designing a workplace or work system in order to minimise risks and optimise performance during normal and emergency operations (Vink et al., 2006).

At the stage of the design process simulated in the training course, there are not yet any technical system interfaces or cognitive work tasks to consider. Hence, the drawing review is performed on a conceptual level, limiting the analysis to physical ergonomic aspects and social environment factors on board. Although not immediately recognised as safety-critical, the living conditions on board can have serious effects on operator and team performance. By ensuring adequate quality of sleeping and eating quarters, as well as possibilities for the crew to have an active leisure time on board, vital psychosocial stressors can be minimised, increasing crew well-being and health (Carter, 2005).

The study in Paper VI described how typical users, in this case 18 nautical cadets from a Merchant Marine Academy, can be employed in a participative design process in the absence of an appointed crew. Despite the cadets' lack of familiarity with the prototypical ship used in the study, they related their relatively short seagoing experience from other ships to the use scenarios and discussed both details regarding the physical design on the bridge and the interplay between operators on the bridge and on deck. Many anecdotes were triggered, indicating that the participants interpreted and evaluated the models and scenarios as real ship bridges during the discussions.

Common for both studies is the potential usefulness of the elicited comments from the participants, generating tangible examples on workspace design, prerequisites for installation, use and service of equipment, transport and evacuation routes, maintenance and cleaning. In both studies, this was achieved through relatively small resources for time, materials for low-fidelity mock-ups and training efforts – especially considering the costs for re-designing a workplace at a later stage. The decisions made during the conceptual and preliminary system design determine the main body of a system's lifecycle cost (Fabrycky and Blanchard, 2004).

Apart from illustrating how knowledge can be developed and transferred between users and designers of shipboard work systems, the outcome of these studies can be discussed in terms of empowerment of participants and inspiring confidence to embark on future design projects in real life. Empowerment does not come automatically from participation, but through a progressive process in which the participants can staircase their understanding of the remote and complex decision processes surrounding a design project. Relations to colleagues and skill discretion (the possibility for an employee to learn new things, utilize skills and creativity, and perform varying tasks) are closely related to perceived stress and mental health (Stansfeld, 2002, Karasek, 1979).

The retrospective study in Paper VII employed a different approach than the former two, investigating the pioneering SCR installations on Swedish ships in terms of decision processes, functionality, knowledge and training. One of the most prominent findings to emerge was the importance of rapport (mutual understanding or trust) between the different actors in the system – manufacturer of the technical system, shipyard who makes the installation, shipowner, cargo owner and operator. Although the study revealed a lack of formal structure for knowledge transfer between these actors, it showed that in the cases where the dialogue was working through less formal channels, so was the SCR catalyst. This is consistent with Guinan (1986) who proposes that communication between designers and users is positively related to the outcome of the design, and Berlin (2011) who identifies rapport-building as an important strategy for influencing workplace ergonomics.

A participative design process involves an expansive learning of all actors involved. The operators convey experience and feedback regarding usage to the designers, and the designers provide understanding of the system's function and operation. This knowledge flow helps to close the feedback loop between end-users and designers – linking the islands of knowledge. A mutual understanding supports the supplier in designing more operable systems, and the operators to operate them more efficiently and reliably (Launis, 2001). A collaborative installation process, involving both operators and technical management contributes towards a deeper understanding of how the SCR works, thus enabling a more efficient operation. This would lead to less time and resources spent on problem-solving and maintenance, which in turn would lessen the exposure to hazardous tasks and substances and improve the reduction of NO_X emissions.

Another challenge on the theme of development and transfer of knowledge is the institutional barriers that come with the prescriptive rules on knowledge and training within the regulatory regimes. The mandatory training courses included in the STCW convention are naturally prioritised before other training courses. Swedish and European work environment legislation require the employer to ensure that the employees' knowledge of the work and any risks associated with the work is sufficient (EEC, 1989, AFS, 2001:1). The same message can be read in the ISM Code, which requires each ship to be *'manned with qualified seafarers'* and the establishing and maintaining of *'procedures for identifying any training which may be required in support of the safety management system and ensure that such training is provided for all personnel concerned'* (IMO, 2010, Chapter 6). This requirement and its relation to the safety management system undoubtedly leaves room for interpretation and a question arises: when does ergonomics management become safety management?

No specific training is required for a technical system (or task) that is not regarded as safety critical. Training is possibly given to the operators who are on board at the initial start-up, and these operators are then supposed to transfer this knowledge to their colleagues and successors. Thus, successful operation of the system depends on the instructor's pedagogical as well as technical skills. Situations in the working life become the arena where the learning and the knowledge transfer occur. Rather than being an event, transfer of knowledge can be conceptualised as a learning process affected by a large number of variables (Eraut, 2004). Depending on the extent to which a new situation resembles previously encountered situations, the learning process may be short and easy, or long and challenging.

In viewing an organization as a knowledge system, knowledge is constantly generated and transformed through different types of bearers: people, machines, technical and administrative systems, documents, computer applications, and so forth (Wikström and Normann, 1994). Hence, for safe and efficient operation and maintenance, the installation in general and its user interfaces in particular, must be designed for good guessability, so it is easy to correctly guess how something works and what happens when for example a certain button is pushed. And further for learnability, so it is easy for the operator to learn how it works and remember correct actions (Jordan, 1998). This is especially important considering the high personnel turnover levels within the industry, with a constant influx of new crewmembers to train.

Recognizing training as an investment rather than a cost in a longer time-perspective than the nearest tour of duty influences employability and attractiveness of work. The positive effects of improved individual and organizational learning will be seen right across the business, since many people in positions at classification societies, marine insurers, ship yards, manufacturers etc. have a background on board.

In summary, there is a large body of knowledge within the maritime domain on how to create successful systems. There is however an absence of formal structures for transfer of this knowledge between the various system actors that causes costly operational disturbances, unnecessary risks for occupational accidents and in the case of green technology installations, harmful emissions to the environment. Strategies must be developed for bridging these islands of knowledge on several organizational and political levels: within international and national legislative regimes, trade organizations in the maritime sector and ship operators. These strategies include improved integration of ergonomics in the pre-operational planning phase of new vessels, workplaces, technical and administrative systems, and early involvement of the sharp end operators. Further, institutional and regulatory arrangements must be made for ensure quality crew training and the retention of maritime know-how, setting a level playing field across all operators and segments in the sector.

5.4 Managing ergonomics in the maritime transport system

The results show that an inherent potential for improvements can be found at the first steps of the human-tech ladder (Vicente, 2004), within the physical and cognitive workplace layout and design of the ship system and its sub-systems. Many ergonomic issues causing accidents and injuries can be solved early in the planning and design phase of new vessels or when planning changes in organization, work tasks or equipment. It is therefore suggested that traditional human factors and design engineering tools, such as methods for task and function analysis, user profiles, anthropometric and heuristic evaluations and user evaluations (e.g. Stanton et al., 2005, Wilson and Corlett, 2005), are used routinely. The use of these tools is equally important for designing the social environment on board. Seafarers of today have evolved into knowledge workers, operating in an increasingly complex socio-technical system that demands high level of concentration during planning, operation and administration of work. With long working hours and composition of watch systems with few hours of rest follows a need for physical and mental recuperation in order to promote personal health and safety and minimise the risks for use errors and accidents by stressed or fatigued operators. However, it is necessary to incorporate ergonomics management at all stages of a development process, whether it is the building of a new vessel or re-design of a workplace.

First, ergonomic factors must be addressed already during the requirement analysis, expanding the framework of *'design for service'*, operationalized for the shipping industry by Veenstra and Ludema (2006). In this framework the operational requirements are summarized in the basic levels of: amount of cargo carried, transit time between ports and suitability to carry a certain cargo. It is necessary to further break down these considerations through a function allocation process, identifying tasks performed by humans, tasks performed by machines, and tasks that are done by humans and machines in interaction. Further, to define workplace and social environment specifications, such as noise and vibration limits in accommodation, transport and evacuation routes, necessary facilities for storage, washing and repair work, etc.

Second, at the stage of basic and detailed design, suggested design proposals are evaluated and approved using more or less advanced models, mock-up or simulations. Here it is paramount to involve end-users. This will ensure valuable feedback on the design, at a stage where it is still feasible to make changes, as well as create a sense of ownership and acceptance of the design. An adequate system design and thought-out human–machine integration contributes toward increased operator efficiency and improved reliability. Undetected problems or issues that are not possible to solve due to technical, social or economic constraints will inevitably follow the ship during its lifetime of operation, commonly for 25–30 years (Stopford, 2009).

Third, in order to prevent and mitigate any risks associated with these problems or issues, work instructions, routines and technical operating and maintenance manuals must be designed for clarity and readability and written in a language understood by the crew. Recognizing the global marketplace for both marine equipment and seafarers, IMO (2007) recommends that IACS *Guide for the development of shipboard technical manuals* (IACS, 2000) is used as a model for shipboard technical operating and maintenance manuals. This recommendation is however not well known in the industry and rarely followed up during internal or external inspections. Strategies for improvement in this area thus need to be developed at both organizational and political level.

The fourth and last resort for remaining unsolved problems or issues lies in training to ensure that the operators understand any risks associated with the work, and increase their knowledge about how these risks can be avoided. Operators also need sufficient knowledge and training of the systems they are set to control so that complex or unexpected situations can be attended and perceived, adequate decisions made and correct actions taken during stressful conditions. In addition, it is important that not only the actual users receive training on how to operate a system and how to avoid accidents and injuries. It is just as important that any risks associated with a particular system or work task are known by the nearest manager so the work can be planned and performed in a safe and efficient manner. The manager is responsible for ensuring that adequate work instructions and work permits are available and adhered to, and that necessary controls of exposures are carried out and that adequate personal protective equipment is accessible and used. Essentially, most crew positions and work tasks at sea can be seen as safety critical. Hence, poor crew performance, irrespective of cause, can lead to increased risks for accidents and damage to environment, cargo and ship.

In sum, ergonomics management contributes towards improved design of systems, equipment and procedures, optimisation of resources (human, material, capital, time), and improved overall systems performance through the following main activities:

- Ergonomics requirement analysis
- Evaluation of design proposals
- Design of usable documentation
- Operator training

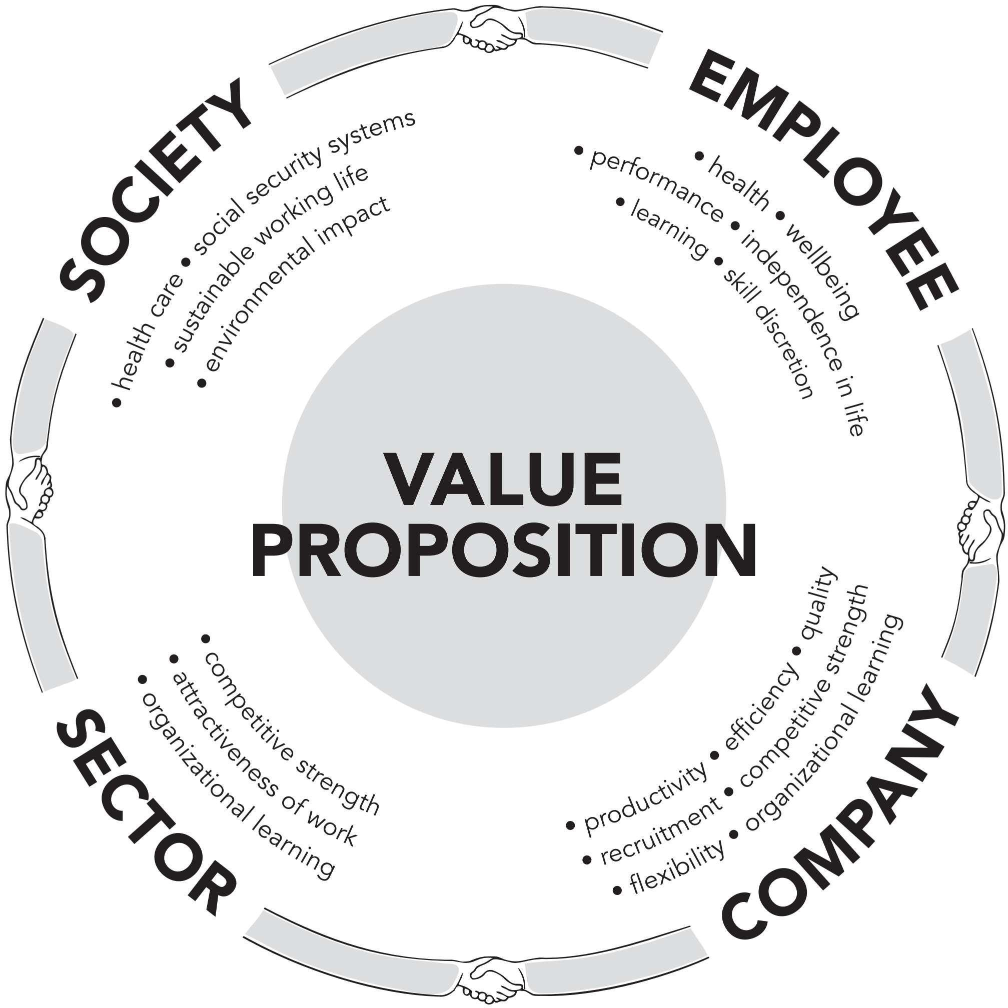

Figure 5 *A value proposition of maritime ergonomics positioning core values of ergonomics at employee, company, sector and societal level.*

5.5 A value proposition of maritime ergonomics

While the ethical and moral cases for a systematic ergonomics management are clear, the preceding analysis shows a case also for business performance. A value proposition of maritime ergonomics is proposed (figure 5), positioning the potential core values of ergonomics that can be delivered at different levels within the maritime transport system: the employee, the ship operating company, the maritime sector, and society as a whole.

Values for the individual include benefits regarding physical and mental health and well-being, but also regarding individual learning and skill discretion. Ultimately, maintaining good health and having the opportunity for personal professional development and career opportunities on board and within the industry contributes to an employee's power to make a living, provide for family and independence in life.

Values for the company include improved operational performance in terms of increased productive time at sea, operational efficiency and improved quality of sea transport services that in turn result in increased operational flexibility and competitive strength. This is achieved through a motivated and well trained crew, more efficient movements in operation and maintenance with reduced costs and time lost for accidents, injuries and operational disturbances, reduced costs for recruiting, less use of energy and other consumables. It is further achieved through improved corporate image affecting the company's ability to keep and attract business, the position on the labour market and attractiveness of positions in the company.

Values for the sector include competitive strength towards other modes of transport on a national and regional basis, attractiveness of work and the sector's ability to recruit and retain competent personnel and recruiting of new personnel to the sector. Values further include increased organizational learning across the industry through a flexible workforce on board and within shore based organizations.

Values for the society include reduced costs for health care and social security. Well operated and maintained systems further reduce the risk for operational and accidental pollution to the environment. Improved physical and psychosocial working conditions, that preserve health and reduce the risks for occupational accidents as well as ill-health, affect the human's ability to perform well during the entire working life, contributing towards a sustainable working life.

The proposed value proposition can be seen as a tool for supporting informed management decisions and a guide for developing operational strategies on political, inter- and intra-organizational levels. It increases the understanding of why ergonomics management is important, to whom it is important and how it is linked to core business values and overall performance of the maritime transport system.

6 DISCUSSION

In this chapter, general and methodological reflections on the results in relation to the research aim are presented. The chapter ends with a discussion on theoretical and practical implications of the main findings and suggestions for further research.

6.1 General reflections

In the value proposition derived from this research work and illustrated in Figure 5, the core values of a systematic ergonomics management work at individual level are described from an employee perspective, acknowledging the importance of a sustainable working life also for independence in personal and family life. At organizational level it was found useful to distinguish between company level, describing values for a ship operator, and sector level, describing values found across the entire industry. The values described at societal level are developed with a global perspective in mind, but the actual value will naturally differ across states and regions due to for instance differences in legislation and how it is enforced, health care and social security policies.

The value proposition is not presented as objectively assessed data. Nor does it pose as an absolute account. Due to the scarcity of previous work in this research area, the results presented in this thesis can be seen as a first piece in the puzzle, a first step to make visible the effects of ergonomics management on overall systems performance in the maritime domain. It is the author's firm belief that increased knowledge of these effects positively influences policy and decision making on political and organizational level towards improved working conditions for seafarers in a safe and sustainable maritime transport system.

There are many references in this work to measuring of various performance indicators and evaluation of effects, but the absence of direct causes and interrelatedness between an acceptable performance representation of a problem and its solutions becomes an impediment. It is a human truism that what gets measured gets done, but it is obviously not the measuring and evaluation activities in themselves that improve performance, decrease environmental impact or make seafaring a safer profession. The advantages of these activities lie in the increased understanding of the system that is achieved through a methodical definition, investigation and assessment of performance and objectives, justifying ergonomics and guiding management and operators on all levels to appropriate solutions.

6.2 Reflections on methods

In 1985, Lincoln and Guba in their discourse on trustworthiness asked (p 290):

> *'How can an inquirer persuade his or her audiences (including self) that the research findings of an inquiry are worth paying attention to, worth taking account of?'*

In response to this question, Lincoln and Guba developed a set of evaluative criteria by which to establish trustworthiness in research:

- Confirmability – a degree of neutrality or the extent to which the findings of a study are shaped by the respondents and not researcher bias, motivation, or interest

- Credibility – confidence in the 'truth' of the findings

- Transferability – showing applicability in other contexts

- Dependability – showing that the findings are consistent and could be repeated

As regards to *confirmability*, it is acknowledged that the research approach and methods for data collection and analysis in the work with this thesis to some extent have been influenced by the researcher's presuppositions. A certain pre-understanding entering a research project can be timesaving if the researcher does not have to read up on structures, procedures, jargon and other peculiarities within a company or industry. Pre-understanding is also said to simplify acquisition of institutional knowledge, such as informal hierarchies, cultural values, social interactions and patterns that can otherwise be difficult to access (Gummesson, 2000). However, since the lens through which we view our world inevitably highlights and obscures various components, there is a risk that pre-understanding leads to preconceptions that block new information, create bias and hamper creativity and innovation (Bryman and Bell, 2007). This aspect has been thoroughly acknowledged during the work with this thesis.

Self-reflexivity and transparency are two valuable means to sincerity in qualitative research and achieve confirmability (Tracy, 2010). Throughout the research process, the researcher has been aware of, and reflected on the subjects of pre-conceptions, the risk for selective perception and personal defence mechanisms, values and beliefs. By explicitly accounting for relevant experiences significant for the pre-understanding, and striving for a thick description of the analysis process and line of argumentation, the researcher has aimed for a transparency to enable readers to form an opinion of the quality and trustworthiness of the present research.

As regards to *credibility* and *transferability*, and in order to obtain a comprehensive understanding of the research area, the research design included triangulation within and across studies, as described by Bryman and Bell (2007). Across studies this was achieved by choosing different perspectives, trying to encompass both macro (Paper II and IV) and micro perspective (Paper VI and VII) on ergonomics in maritime operations, and also by having the opportunity to cooperate with several other researchers with different areas of expertise and research foci. Within studies, triangulation was achieved by a combination of data collection methods such as focus group interviews, semi-structured and structured individual interviews, as well as content analysis of literature and documents.

Since the data collection in this thesis work is based on a limited number of group and individual interviews, informant participation is important in that the informants are honest, consistent, keep to the subject and give comprehensive answers (Kvale, 1997). There is a possibility during interviews that the informants might offer answers and reflections that put themselves and/or the companies they represent in a good light. This possibility has been considered and a critical approach has been strived for in the analysis of the empirical data. The selections of informants have been purposeful rather than random in all studies, but it is acknowledged that far from all possible stakeholders have been included. To the extent that qualitative research results at all can be generalised, the thesis work deliberately included different stakeholders with various responsibilities within maritime operations. The informants represent diverse views and perspectives to ergonomics in the maritime domain and the level of experience and competence vary. The fact that the informants agree on the salient ergonomic factors to such a large extent does at least point in a certain direction.

The research work is limited in transferability due to its clear Swedish focus with the boundaries set by prevailing national and regional regulations and conditions. But, with the onset of the increased regulation of environmental and social issues (importantly the implementation of the Maritime Labour Convention and the revised MARPOL convention) the results are relevant also from an international perspective, underlining the need for a systems approach in vessel design and operation.

As regards to *dependability*, this has been achieved primarily through a continuous presenting of results during the entire research process at national and international scientific and industry conferences and seminars. These events have provided opportunity for external researchers not involved in the studies to examine and discuss the research process, data and analysis. The researcher has also strived for a comprehensive description of the context in which the studies have been performed and how the research process has evolved.

6.3 Theoretical and practical contributions

This research work as a whole contributes with theoretical reflections and practical suggestions to the field of maritime ergonomics science, yielding new insights in the area of ergonomics impact on crew and operational performance. The results further the importance for ergonomists and Human Factors specialists to address core business values when seeking acceptance for ergonomics management in the maritime domain. It is important to show that ergonomics management not only contributes to 'comfort', however essential, but that ergonomics have immediate and long-term effect on business.

In this discourse, it is valuable to have domain specific arguments to complement generic models for estimating ergonomics effects on performance. The proposed value proposition forms a knowledge base for an organization to create its own metrics that fit the company's situation and support informed management decisions. Understanding why ergonomics management is important, to whom it is important and how it is linked with system performance and core business values will provide a context for benchmarking and building of rapport across the industry.

Although the maritime domain is unique in many respects, similarities can be found in other industries in which the research results can be applicable. Two examples are the construction industry and the road haulage industry. Both these industries share some distinct features with the shipping industry. For instance, they are of a competitive and risky nature, and involve a multitude of stakeholders on various levels with occasionally conflicting objectives, and have a mobile, often multinational workforce. Thus, it is believed that the developed value proposition can be applied also within these domains.

6.4 Suggestions for further research

There is a lack of complementary quantitative studies to empirically test the links between maritime ergonomics and operational performance proposed here. However, this thesis work constitutes a solid base for the design of future studies in knowing what to measure and how.

Complementary studies are needed to investigate the feasibility in incorporating ergonomics methods and techniques in the toolboxes of naval architects, ship designers and suppliers of marine equipment. Continued research is also needed on the topic of crew participation on all stages in the development process when designing vessels, workplaces or other technical or administrative systems.

Furthermore, in order to encourage improvement actions it is desirable to complement the reactive focus on accidents and injuries with a proactive stance and examples of best practise within the maritime domain.

7 CONCLUSIONS

This chapter summarises the most important findings from the thesis work.

The research work presented in this thesis proposes a link between ergonomics and the value creating process in the maritime transport system, and contributes with theoretical reflections and practical suggestions to the field of maritime ergonomics science.

The following conclusions are drawn from the work:

- Beyond the costs for absence due to sickness, there is a lack of awareness within the Swedish shipping industry on the economic effects of ergonomics, indicating a need for suitable methods in this respect.

- Main focus of research on the maritime domain has so far been on physical and to some extent cognitive ergonomics and safety factors, while an increased concern with organizational factors was noted among the practitioners that participated in the study.

- There is an absence of formal structures for development and transfer of ergonomics knowledge between the various stakeholders in the maritime domain. This absence increases the risk for accidents, operational disturbances, and unnecessary emissions of harmful pollutants to the marine environment.

- The following strategies for facilitating the development and transfer of ergonomics knowledge within the domain were identified:

  - Improved integration of ergonomics in the pre-operational planning phase of vessels, workplaces, and other technical and administrative systems

  - Early crew participation in design processes

  - Improved integration of ergonomics in the design of usable system documentation

  - Institutional and regulatory arrangements to ensure quality crew training and the retention of maritime know-how

Finally, in order to support informed management decisions and highlight the potential value of maritime ergonomics a value proposition was developed and structured around the employee, company, sector and societal levels.

Values for the employee include improved health and well-being, learning, performance, skill discretion and ultimately independence in life.

Values for the company include increased operational performance in terms of productivity, efficiency and quality, advantages in recruiting and retaining personnel, increased flexibility, and organizational learning.

Values for the maritime sector include competitive strength, attractiveness of work and increased organizational learning across the industry.

Values for the society include reduced costs for health care and social security, reduced risk for accidental and operational impact on the environment, and a systematic work towards a sustainable working life.

The value proposition can be visualised as in figure 5 in chapter 5.5.

Suggestions for further work include complementary studies to investigate the feasibility in incorporating ergonomics methods and techniques in the toolboxes of naval architects and other system builders. Further work is also needed on the topic of crew participation when designing vessels, workplaces or other technical or administrative systems.

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