Operation of Vessel Traffic Services
covering international passages
An empirical and process-oriented analysis towards the optimization of vessel traffic management in longer tidal waterways

by

MSC ILKNUR COLMORN

A thesis submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy
in International Logistics

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Statutory Declaration

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22/01/2018 Ilknur Colmorn

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Acknowledgements

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Summary

Based on the research question about how to improve traffic in longer tidal waterways in terms of efficiency and risk mitigation, it is the objective of this PhD Thesis to approach an analysis towards the optimization of the Vessel Traffic Management (VTM) in longer tidal waterways. The theoretical relevance of this objective is the result of a lack of research to model, e.g. the sequence of vessels in waterways, for optimizing the entire traffic flow. The practical relevance of this objective is shown by using the River Elbe of the Port of Hamburg as an exemplary subject of interest for longer tidal waterways, because it is argued that the River Elbe is the most complicated river in Europe. Its dynamics and uncertainties of the waterway with recent developments in vessel sizes makes the traffic organisation more and more complex so that the VTM should be adapted to these increased challenges to support efficiency and safety. It is discussed with the help of the framework of Systems Engineering that such an adaptation needs a holistic perspective and must comprise the positioning of the problem-solving capacity of the current organization of the VTM regarding the external requirements in terms of the complexities of the system. Therefore, it is concluded that the development of a generic model is needed that can serve as the basic for a computer-based traffic prediction and management for the support of decision-making within a system of increasing complexity. To develop such a generic model, expert interviews are selected as the research methodology for the empirical data collection. The empirical data collections point towards the conclusion and thereby, confirm the predefined hypotheses that an overarching comprehensive system or approach that is consistent and reliable is needed, because of the decentralized decision-making processes in the context of a high informal, dynamic and complex environment. With the help of the framework of the Business Process Modelling (BPM), the entire waterway-traffic-environment-system of the Rive Elbe is depicted and illustrated. The analysis of these process diagrams helps moving towards creating a precise system and optimizing the complexity of it. As a result, a conceptual model is outlined towards a computation optimization for a computer-based traffic prediction and management for the support of decision-making. Finally, it is discussed that the future research should
focus on a re-design of the organisation solution of the VTM by using the Quality Function Deployment (QFD) method to ensure certain quality standards.
Table of contents

Statutory Declaration.................................................................................................................. I
Acknowledgements ...................................................................................................................... V
Summary........................................................................................................................................ VI
Table of contents .......................................................................................................................... IX
List of figures .................................................................................................................................. XII
List of tables .................................................................................................................................... XIV
List of abbreviations ..................................................................................................................... XV

1 Introduction ................................................................................................................................. 1
   1.1 Research question .................................................................................................................. 1
   1.2 Practical and theoretical relevance ....................................................................................... 3
   1.3 Research objective ............................................................................................................... 8
   1.4 Structure of the dissertation ............................................................................................... 10

2 Analysis of the research problem ............................................................................................... 13
   2.1 Background about the Vessel Traffic Management in longer tidal waterways ......................... 14
   2.2 State of the art and current traffic organization by using the waterway-traffic-environment-system of the River Elbe ......................................................... 27
   2.3 Deductions from systems engineering towards the research objectives ................................ 33

3 Empirical data collection through expert interviews ....... 40
   3.1 Concept and design of the research methodology for the empirical data collection ........................ 41
   3.2 Results of the expert interviews and workshops ..................................................................... 48
   3.3 Deduction of findings towards the research objectives ......................................................... 52

4 Process modelling ......................................................................................................................... 58
   4.1 Concept and idea of the research methodology of the process modelling .................................. 59
   4.2 Results of the process modelling – descriptions and diagrams of the incoming and outgoing traffic processes ................................................................................... 61
   4.3 Deduction of the findings towards the research objectives .................................................... 77
5 Conceptual outline towards a computational optimization ................................................................. 80
  5.1 Conceptual outline ........................................................................................................................ 80
  5.2 An entity-relationship model ........................................................................................................ 85
  5.3 Quality Function Deployment (QFD) method for future research .............................................. 98
6 Concluding remarks ............................................................................................................................. 101
7 Appendix ............................................................................................................................................. 105

Expanding the outline:

- Expert interview 1 – Ben Lodemann, Hamburg, 20 February 2015 .................................................. 105
- Expert interview 2 – Jörg Pollmann, Hamburg, 12 March 2015 ..................................................... 106
- Expert interview 4 – NTK, Hamburg, 5 June 2015 ........................................................................ 111
- Expert interview 5 – Jörg Pollmann, Hamburg VTS Centre, 24 June 2015 ................................. 113
- Expert interview 6 – Harbour Pilots, Hamburg, 29 June 2015* ................................................... 114
- Expert interview 7 – Rolf Ehlers-Maaßen, Brunsbüttel, 5 August 2015 ..................................... 116
- Expert interview 8 – WSA Hamburg, Frank Richters, Hamburg, 18 August 2015 ................................. 119
- Expert workshop – WSA Hamburg, Hamburg, 7 March 2016 ...................................................... 123

Tables for process description with more information .................................................................. 126
References ........................................................................................................................................... 138
List of figures

Figure 1-1: Illustration of the research objective .................................................. 9
Figure 1-2: Structure of the thesis ........................................................................... 10
Figure 2-1: Overview Chapter 2 ............................................................................. 13
Figure 2-2: Most relevant factors for the Vessel Traffic Management ........... 24
Figure 2-3: System elements and its environment .............................................. 34
Figure 2-4: Underlying idea from Systems Theory ............................................. 36
Figure 2-5: Conclusions for the research objective ............................................. 39
Figure 3-1: Overview Chapter 3 ............................................................................. 40
Figure 3-2: Research methodologies for the data collection ......................... 42
Figure 3-3: Logical relations of the phases of the interviews ......................... 44
Figure 3-4: Illustration of the underlying theoretical framework ..................... 57
Figure 4-1: Overview Chapter 4 ............................................................................. 58
Figure 4-2: Introduction of the business process modelling ......................... 60
Figure 4-3: Process diagram for the incoming traffic (DIN A3) ...................... 73
Figure 4-4: Process diagram for the outgoing traffic (DIN A3) ....................... 75
Figure 5-1: Computation ...................................................................................... 81
Figure 5-2: Concept for the output ...................................................................... 82
Figure 5-3: Concept for the input ........................................................................ 83
Figure 5-4: Concept for the conditional statements .......................................... 84
Figure 5-5: Illustration of the domain Entity-relationship model for HPA (DIN A3) .............................................................................................................. 87
Figure 5-6: Illustration of the Entity-relationship model for the other VTS Centres (DIN A3) .......................................................................................................... 89
Figure 5-7: Illustration of the integrated Entity-relationship model (DIN A3) ................................................................................................................................. 91
Figure 5-8: Illustration of the proposed solution (DIN A3) .............................. 93
Figure 5-9: QFD framework for future research with reference to (Vorbach, 2007, p. 335).
List of tables

Table 1: Listed influential factors on the VTM according to (Froese, 2015) ....................................................................................................................... 23

Table 2: Overview of the expert interviews .......................................................... 47

Table 3: Incoming traffic process description ....................................................... 66

Table 4: Outgoing traffic process description ...................................................... 72

Table 5: Incoming traffic process description with more information .................. 131

Table 6: Outgoing traffic process description with more information 137
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>Air Draught</td>
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<tr>
<td>AGF</td>
<td>Außergewöhnlich große Fahrzeuge (extraordinarily big vessels which means vessels with a length of more than 330 meters or with a beam (width) of more than 45 meters)</td>
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<tr>
<td>AIS</td>
<td>Automatic Identification System</td>
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<tr>
<td>ATA</td>
<td>Actual Time of Arrival</td>
</tr>
<tr>
<td>Bft</td>
<td>Beaufort, a measure for wind speed</td>
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<tr>
<td>BPM</td>
<td>Business Process Modelling</td>
</tr>
<tr>
<td>BPMN</td>
<td>Business Process Modelling Notation</td>
</tr>
<tr>
<td>CTB</td>
<td>Container Terminal Burchardkai (A terminal operated by HHLA)</td>
</tr>
<tr>
<td>DAKOSY</td>
<td>Datenkommunikationssystem AG – A Software Company</td>
</tr>
<tr>
<td>DGPS</td>
<td>Differential global positioning system providing correction of satellite-based position by correction of signal speed from land-based reference stations</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision support system</td>
</tr>
<tr>
<td>Ebb/Flood</td>
<td>Are two phases of the tide or any similar movement of water. The ebb is the outgoing phase, when the tide drains away from the shore; and the flood is the incoming phase when water rises again.</td>
</tr>
<tr>
<td>ECDIS</td>
<td>Electronic Chart Display and Information System</td>
</tr>
<tr>
<td>EGNOS</td>
<td>European Geostationary Navigation Overlay Service, a European DGPS to augment satellite-navigation for increased accuracy</td>
</tr>
<tr>
<td>ETA</td>
<td>Estimated time of arrival</td>
</tr>
<tr>
<td>ETD</td>
<td>Estimated time of departure</td>
</tr>
<tr>
<td>FLZ</td>
<td>Feeder Logistik Zentrale</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System, satellite-based</td>
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HHLA  Hamburger Hafen und Logistik AG – A transportation and logistics company
HPA  Hamburg Port Authority
IMO  International Maritime Organization
Kt/Kts  Knot/Knots. Nautical speed measure, 1 knot = 1.852 km/h
IALA  International Association of Marine Aids to Navigation and Lighthouse Authorities
INCOSE  International Council on Systems Engineering
INS  INformation Services in the context of VTS
MAS  Multi-Agent System
NAS  Navigational Assistance Service (in the context of VTS)
nm  Nautical mile
NTK  Die Nautische Terminal Koordination
ISIMAT  Interaktives Schiffsverkehrsmanagement-Tool
PPU  Portable pilot unit
PRISE  Port River Information System Elbe
ROT  Rate of turn
SE  Systems Engineering
QFD  Quality Function Deployment
TEU  Twenty Foot Equivalent Unit, standard container size of 20´ x 8´ x 8´
TOS  Traffic Organisation Service (in the context of VTS)
UKC  Under Keel Clearance
WSA  Wasserstraßen- und Schifffahrtsamt
VHF  Very high frequency, the marine mobile band covers the frequencies between 156.0 and 162.025 MHz
VTS  Vessel Traffic Service
1 Introduction

1.1 Research question

Tidal waterways\(^1\) are dynamic systems and the management of vessel traffic on long tidal waterways is a highly complex task, because when assessing the navigability of longer tidal waterways many conditions must be considered.\(^2\) For example, in a tidal waterway tide impact works positively when sailing upstream a river towards a port as the ship speed benefits from the raised water level and keeps pace with the tide progress from the open sea towards the port. When departing from the same port, heading towards the open sea it becomes more complicated as the low tide travels from the sea towards the port and the vessel can only benefit from the raised water level during a brief time window from the raised water level. Therefore, for tidal ports the departure time window is narrower than the arrival time window. Due to other external factors, e.g. wind direction and force, the water level might not increase at the expected rate resulting in unplanned waiting time or cut and go earlier for the vessels at the berth. This would automatically affect the incoming traffic as well. Accurate calculation of exploitable time windows is therefore essential. In this regard, further factors are often mentioned making a tidal waterway more complex:\(^3\)

- Vessels with their dimensions, equipment available onboard to support navigation in coastal areas, manoeuvrability and their itinerary is another challenge for the longer tidal waterways in many aspects.
- Waterway itself with its morphology, navigable water depth, width, allowance on speed and air draft as well as the dynamic conditions is one of the other important components of the waterway-traffic-environment.

---

\(^1\) According to the (Dictionary, 2016) a waterway is a route, e.g. a canal that ships can sail along, or a river, canal or other body of water serving as a route way of travel or transport.
\(^2\) Cf. (Agerschou, et al., 2004) & (George, 2013)
\(^3\) (Froese, 2015). Cf. also section 2.1 in detail.
• Traffic nature and the density create risk factors to be considered.
• Tide and current as mentioned above as well as the weather conditions affect the navigation in a fairway.
• National regulations are usually compatible to international regulations; however, national conditions may require some modifications and amendments.
• Logistics, meaning the flow of cargo to and from a port and terminal, is another important component of the waterway-traffic-environment. Delivery and picking up time of containers depend on the estimated times of arrival (ETA) of vessels. ETA triggers the processes beyond the navigation.
• Finally, the efficiency and safety of navigation depend also on the skills, knowledge and attitudes of all stakeholders involved on board and at shore.

Therefore, it is necessary to investigate and elaborate a wide set of relevant parameters when managing vessel traffic. Because of this wide set of relevant factors, interacting with each other, the navigational risks are difficult to assess making the traffic management in a longer tidal waterway becomes even more complicated.

Against this background the following research question arises:

| Research question | How to improve traffic in longer tidal waterways in terms of efficiency and risk mitigation? |

The result of such an investigation and elaboration should reveal the interdependencies between all entities involved that would lead to identifying further development opportunities for the vessel traffic management.

To figure out whether this research question is of importance for industrial applications as well as for the scientific world the practical and theoretical relevance are shortly discussed.
1.2 Practical and theoretical relevance

Commodities and capital are moved freely by free trade agreements. This increases the world trade and global exchange of goods which is dependent on the effective and efficient transport systems. Ships move the biggest share of these goods internationally. The invention of container boosted global economy dramatically by lowering the cost per unit (Froese, 2015). Thus, the vessel sizes continue to grow to further benefitting from economies of scale and facilitating the global economy. However, ship sizes resulted in challenges such as infrastructure, equipment, peaks in traffic amongst others (ITF/OECD, 2015). The question is to facilitate trade by using the existing capacity of infrastructure to its maximum until long-term infrastructure adaptations take place. One way is to facilitate the increased use of waterways, which are the gateways to the ports. Therefore, the research question with its focus on longer tidal waterways has significant relevance for the industry, the economy and the ports (Froese, et al., 2006).

In this regard and although not being a new topic, the increase in the ship sizes has been accelerated in the last decades. Shipping lines are in continuous fierce competition to gain a competitive advantage by economies of scale and hence lower costs per unit transported. This means to build always-bigger vessels. This creates an effect on the overall maritime transport chain (ITF/OECD, 2015). Ports face the challenges already and are trying to keep pace with ship development not to lose business. This is a special challenge for the ports which are not adjacent to open sea. Because it requires navigating through a long waterway. The capacities of the waterway cannot increase as the same pace as the dimensions of the vessels, causing increasing concerns about the safety of navigation (Froese, 2015). As a result, the question of how to gain efficiency and how to cope with the navigational risks is still an open and important one.
Hamburg provides a good example for this. In 2014 the Port of Hamburg was called by 972 of the large vessels (330m length and 45m beam and above). The plan of future ship orders show that the number of these vessels will additionally increase in the next 2 years up to 40% (Interview 2, 2015). The biggest constraints that the increased size vessels create are the draft and the width. To get into the Port of Hamburg, vessels needs to navigate through a waterway that is about 108 km from Hamburg to Cuxhaven, the longest one in Europe. Large container vessels must match their sailing plan to the course of tide and to other traffic to safely navigate up and down the river. There are cases where the vessels either wait at the entrance in the North Sea or at the berth due to not sufficiently increasing water level which can be caused by some external factors, such as wind reducing the tide level. This results in waiting for the needed level of water or letting some cargo be discharged, if not manageable by discharging ballast water, in order to depart with less draft. Furthermore, the increased width of new generation vessels creates another issue to deal with. There are areas in the waterway where 2 large vessels may not be able to pass each other. Therefore, the Port of Hamburg has a complex and dense traffic with sea-going, inland-waterway and port operating vessels at the port area (Vessel Traffic Service Hamburg, 2015). There are tidal current, areas restricted for encountering, dredged channel for large vessel, the Köhlbrand Bridge and shallow water areas. As one of the most complicated and difficult to navigate waterways in Europe, the Port of Hamburg and the River Elbe will be investigated in detail. It will help to create a general approach which will be applicable to all longer tidal waterways.

Consequently, by using the River Elbe of the Port of Hamburg as an exemplary subject of interest for longer tidal waterways the practical relevance of the research question is shown because it also must deal with the above-mentioned increased navigational risks and the complexity of the traffic management.
Nevertheless, the investigations of this thesis are targeted to be generally applicable, but the River Elbe shall serve as a baseline scenario from which general rules can be concluded. Because of the gap of knowledge regarding cause and effect relations must be identified on the specific level of the baseline scenario. Therewith the theoretical relevance on the generic level of the traffic management in longer waterways can be captured, too.

In 2009 the Maritime Logistics Workgroup on the topic of Vessel Traffic Services (VTS) conducted a workshop at Jacobs University. The workshop aimed at a view into the future of VTS as original service and as a component of new services by freely exchanging ideas amongst experts from all over the world. The scope of the workshop was wider and touched on many interesting issues related to traffic management. Among these, the following 3 outcomes for the exchange of ideas are valuable for this research:

1. The strategic potential of VTS to plan traffic allocation in restricted areas in advance or for contingency planning is acknowledged generally but realised on distinct levels.
2. There is a need for quantitative research to provide algorithms for decision support tools for VTS operators to decide on an optimum sequence of vessels.
3. “Providing opportunities for improving the efficiency of transport and logistics” needs further investigation and calls for organisational concepts to not mingle public tasks with commercial interests.

Therefore, these outcomes outline the need that VTS can improve cooperative resources management and planning. This is to be carried out via traffic organization (Froese, 2009) that is still lacking essential improvements within the above-mentioned three areas.

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4 The terminology of Vessel Traffic Services (VTS) will be clarified in section 2.2.
### Project 1: ISIMAT

In 2002 there was already evidence that the percentage of very large vessels will continuously increase and pose a problem for managing the waterway traffic. The German Ministry of Education and Research therefore awarded a research contract to a consortium composed of Atlas Elektronik GmbH (VTS Manufacturer), Institute of Ship Operation, Sea Transport and Simulation ISSUS and BLG Consult. The project duration was from 2003 to 2005 and the research part “interactive vessel traffic management tool” was conducted by ISSUS (Froese, et al., 2006). The ISIMAT project concluded that the view from the own ship to the whole traffic to become encountered during the whole waterway passage is lacking regarding research models in which the underlying relations are appropriately reflected.

### Project 2: PRISE

In the view of the increasing number of large vessels, resulting in complex traffic processes along the waterway, it was decided to develop an IT-platform to optimize sequencing and arrival of mega-ships on the River Elbe and at the Port of Hamburg, the Port River Information System ELBE, in brief PRISE (DAKOSY, 2015). The project consortium under the leadership of DAKOSY was composed of the terminal operators HHLA and Eurogate, the Elbe Pilot Association and Hamburg Port Authority. The work commenced in 2011 and was concluded in 2013, then followed by a one-year test bed and finally the operational system launched in March 2014. The terminal operators HHLA and Eurogate as well as the operative platform financed the project. PRISE allows the terminals to plan ahead, to react on changes of ETA on short notice and to apply optimized cooperative resource planning. It is necessary to follow up and ensure continuous improvement as for a proper functioning information platform it is crucial to achieve 100% participation of all vessels and entities. This is the pre-requisite for an optimization goal. As information systems are the main supporters of logistics and traffic processes, it shows the theoretical relevance of the research question because it also points to a lack of the modelling of all the relevant cause-and-effect-relations.
There is a lack of research to model the sequence of vessels in waterways with the objective to optimize the entire traffic flow.\textsuperscript{5} Also cf. further and deeper introduction in (Agerschou, et al., 2004), (Bichou, 2009), (Bichou, 2009), (Alderton, 2008), (Kim & Günther, 2007) & ( Bölse, 2011).
1.3 Research objective

Setting the course

There have been several initiatives, projects and test beds carried out as briefly explained under theoretical and practical relevance of the subject. With reference to (Froese, 2015) the general tendency has been to improve current traffic management without re-inventing the entire system. Advanced technology is available to provide solutions to exploit the capacity of waterways. However, many waterways are reaching their limits that do not allow for further deepening and/or widening for many reasons. Therefore, a more intelligent use of existing waterways and ports is the only way to grow economically. In the light of this reality, there is a need for a vision that will drive the development into this direction.

Objective

Consequently, the objective is set to approach an analysis towards the optimization of the Vessel Traffic Management in longer tidal waterways (cf. Figure 1-1).
Figure 1-1: Illustration of the research objective

Trends
- Increased number of big vessels (economies of scale)
- Imbalance between capacity and demand
- Longer waiting times, congestion and lower efficiency in operations

Restrictions
- Waterway
  - Geometry
  - Draft allowances
  - Speed allowance
  - ...
- Vessel
  - Dimensions
  - Speed
  - No. of vessels
  - ...
  - Etc.

Gaps of knowledge about the complex interactions of influential factors for improving the Vessel Traffic Management

The objective is set to approach an analysis towards the improvement of the Vessel Traffic Management in longer tidal waterways.
1.4 Structure of the dissertation

Chapter 1

Chapter 1 has provided a very general overview of the research perspective and its background. To reach the outlined objective this dissertation will follow the structure below that is also approached in Figure 1-2 below.

Figure 1-2: Structure of the thesis

| 6. Concluding remarks | - Summary
- Discussion of the contributions and limitations
- Outlook for future research |
| - Introduction into the research methodology
- Design of the proceedings
- Outcomes
- Deduction of findings towards the research goals |
| 3. Field interviews | Solution approach |
| 2. Elaboration of the research problem | - State of the art and background
- System-based theoretical framework
- Analysis for the research problem |
| 1. Introduction | - Research question and its practical and theoretical relevance
- Substantiation of the research objective
- Structure and research methodologies |
| 4. Process modeling | Solution approach |
| 5. Conceptualization | Solution approach |

Chapter 2

Chapter 2 will introduce the scientific perspective about how to look on the subject of interest. The reason for this is that a scientific work such as this PhD Thesis must explicitly outline its underlying assumptions, methodological proceedings etc. because these determine the outcome of every scientific consideration. As a result, the traffic flow of a river (here the River Elbe as an exemplary subject of consideration) will be presented and defined from a system-based perspective. This includes examining the waterway-traffic-environment and its components in a detailed way. It is
necessary to go deep into the current needs of the industry to be able to identify underlying problems and progressing towards future development. Moreover, without understanding the traffic system itself, in this case a waterway and the traffic management, it is not possible to identify improvement opportunities. Therefore, one of the most complicated waterways in Europe, River Elbe – Port of Hamburg, will be identified, described and examined from a system theory-based perspective to capture all relevant conditions. To do so, the following structure is proposed for elaborating or analysing the research problem:

- Section 2.1: Background about the Vessel Traffic Management in longer tidal waterways
- Section 2.2: State of the art and current traffic organization by using the waterway-traffic-environment-system of the River Elbe
- Section 2.3: Deductions from a systems engineering point of view towards the research objective

As a solution method, an empirical analysis via expert interviews and workshops are conducted for bridging the identified gap of knowledge with the help of the case study approach of the River Elbe. This includes a literature review as well as a review of project work results to bring out some questions for the interviews. With the help of the interviews and their inductive approach to capture all conditions conclusions can be drawn towards the research question. Hereby, the conclusions will point out the need for a system-based perspective so that the whole traffic is optimized instead of providing individual solutions.

The results of this empirical analysis are applied with the second solution method by presenting the findings from a process point of view. Process modelling supports capturing relevant activities of the organization and allows the identification of interdependencies and freedom of decision-making for all involved entities. The overall objective of the process approach is to be able to firstly move towards a system-based perspective and secondly to present the entire system. The processes are derived mainly from the Chapter
3; the detailed problem elaboration and the interviews done as bottom-up approach. As a result, conclusions in terms of rules or restrictions are derived.

Chapter 5

The fifth chapter will conceptualize the results towards a tool for the optimization of the decision-making. Based on the findings of the second, third and fourth chapters the results will be integrated for understanding the next steps in future research, i.e. how to mathematically model the optimization. As a result, a conceptual entity-relationship model is developed for presenting the current status of traffic management in longer tidal waterways, which identifies how to enable a system-based perspective.

Generally, the Chapters 3, 4 and 5 can be characterized as a solution method because they represent the effort to find a solution or answers towards the research problem that will be analysed in Chapter 2. Moreover, they constitute the own research of the writer of this PhD thesis so that comprise innovative research for bridging the identified gaps of knowledge. Against this background the three Chapters follow the same structure due to their similar characteristics:

- Section x.1: Concept and design of the research methodology
- Section x.2: Results of the research methodology
- Section x.3: Deduction of findings towards the research goals.

Chapter 6

The last chapter will summarize and discuss the findings and innovation aspects of this thesis including the contributions and limitations. The processes are aimed to be generally applicable and most importantly to be the basis for the generic model that is to be developed in future research including a data model and simulation.
2 Analysis of the research problem

As has been outlined in the introduction the framework for the analysis of the research problem will be introduced so that it’s concept and the design will be outlined. At the end of the chapter findings towards the research objectives are deduced (cf. Figure 2-1) against the background of a theoretical framework that fits to the outlined requirements.

Figure 2-1: Overview Chapter 2
2.1 Background about the Vessel Traffic Management in longer tidal waterways

This section aims at showing the state of the art of vessel traffic management in longer tidal waterways. When assessing the navigability of longer tidal waterways that is essential for their management, many factors must be considered. These factors are elucidated below according to (Froese, 2015):

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sub-categories</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel</td>
<td>Dimensions</td>
<td>Dimensions of the biggest container vessel as of today⁶:</td>
<td>Not the end of development. Shipyards have orders of container vessels up to 22,000 TEU. Increase of the length and the beam while the draft stays mostly constant (ISL, 2014).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Length 400m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Beam 59m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Draft 16m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Height 73m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Carriage capacity: 20,100 TEU</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td>• Two-axis speed sensor (through water and over ground)</td>
<td>Generally, accurate navigation in coastal areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Heading indicator (gyro)</td>
<td>Minimum requirements are not always satisfactorily met</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rate of turn indicator (ROT)</td>
<td>Invention of portable pilot units (PPU)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• DGPS (position accuracy within decimetre range)</td>
<td>A ruggedized laptop provides the processing and display platform to operate tools as ECDIS, AIS and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High resolution echo sounder</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ECDIS, i.e. the maritime geographical system</td>
<td></td>
</tr>
</tbody>
</table>

⁶ (Port Technology, 2015).
### Analysis of the research problem

| **Manoeuvrability** | **Radar**  
| | Automated identification system (AIS) allowing the tracking of vessels (IMO)  
| | Communication to other vessels and shore-based services  
| **Manoeuvrability** | **Track-keeping ability of a vessel depends on propulsion and steering means**  
| | Propeller and rudder as basic configuration  
| | Combined when providing propulsion and steering by azimuth drives.  
| | Bow thrusters for improving manoeuvrability  
| | Tugs for assistance and providing external propulsion and steering forces.  
| | The safe minimum steering speed also depends on wind  
| **Manoeuvrability** | **Generally, accurate navigation in coastal areas**  
| | For a container vessel sailing under 7 – 8 Bft abeam wind, the safe minimum steering speed will be around 7 knots.  
| | A speed of 7 knots may already cause squat problems in areas of small underkeel clearance and the vessel command must solve the conflict between safe minimum steering speed and squat effects.  

**Additional information:**  
- **Radar**  
- **Automated identification system (AIS)** allowing the tracking of vessels (IMO)  
- **Communication to other vessels and shore-based services**  
- **PPUs** are frequently combined with two DGPS sensors temporarily mounted on the ship’s bridge, thus providing ship’s speed and ROT independent from vessel’s equipment.  
- In case there is a pilot-plug available on the bridge to link a PPU to the vessel information system, the full range of vessel movement information will also be displayed.
### Analysis of the Research Problem

<table>
<thead>
<tr>
<th>Itinerary</th>
<th>Waterway Morphology</th>
<th>Depth</th>
</tr>
</thead>
</table>
| • Big vessels do not just have to sail up a fairway and berth at a terminal.  
• A berth must be available and assistance services, such as pilotage, tug assistance and mooring teams | • Appropriate fairway depth and width as a precondition of safe navigation  
• Waterways normally provide an irregular morphology resulting sometimes fast changing hydrodynamic forces upon the ship’s hull | • Minimum water depth for safe navigation  
• Immersion of ship hull (draft) |
| Liner ships sail according to an itinerary but adverse weather conditions and delays in prior ports often result in a change of the ETA complicating the performance of the complex processes around a vessel’s port arrival. | As hydrodynamic effects depend on the vessel speed, morphologic conditions may require reduced speed. | • If not in calm waters possible rolling, heaving and pitching, increasing the draft must be |
| Water density depending on salinity and temperature | considered. Ship’s draft in shallow water also is increased by squat (increased immersion caused by dynamic pressure effects) depending on speed. |
| Trim as the difference between forward and after draft | The margin of safety in navigable water depth is called “underkeel clearance” and is not a fixed value but depends on actual conditions as expected tide, wind speed and direction and manoeuvre speed. It is common under normal conditions to determine the underkeel clearance by 10% of the vessel’s draft. A vessel sailing at 14.5 m draft then requires a water depth of minimum 16 m for safe navigation. |
| List i.e. the heeling angle | Benefitting from raised sea level by tide impact works well when sailing upstream a river towards a port as the ship speed usually allows keeping pace with the tide progress from the open sea towards the port. |
| Tide height including wind impact on water level | |
| Uncertainties of tide prediction, soundings and chartings | |
When departing from same port, aiming at the open sea it becomes more complicated as the low tide travels from the sea towards the port and the vessel can only benefit a brief period from the raised water level. Therefore, for tidal ports the departure time window is narrower than the arrival time window. Accurate calculation of exploitable time windows therefore is essential.

<table>
<thead>
<tr>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Longer tidal waterways are marked by buoys, but this does not mean that the maximum draft allowance is valid for the whole fairway as there are often channels dredged providing less width than the fairway.</td>
</tr>
<tr>
<td>• Dredging of longer tidal waterways is very costly and waterway authorities therefore try to minimize efforts resulting in a channel within the waterway just</td>
</tr>
<tr>
<td>• Bank effect, asymmetric water flow caused by the proximity to the channel bank, results in a suction effect towards the bank and a turning momentum away from the bank which in the worst case may result in loss of ship’s controllability</td>
</tr>
<tr>
<td>• Ship-to-ship interaction, when ships overtake each other or meet, high and low-pressure areas of both ships are adding up to pushing off,</td>
</tr>
<tr>
<td>Meeting vessel navigational requirements.</td>
</tr>
<tr>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Big ships can only use parts of the buoyed longer tidal waterways and therefore are dependent on highly accurate navigation as there can be on special marking of the dredged channel which would hinder all other traffic.</td>
</tr>
<tr>
<td>A channel width of 300 m is common for dredged channels and when considering a vessel beam of around 50 m in an encountering situation with a vessel of the same size, results in a passing distance of only 100 m when both ships maintain 50 m distance from the channel border. With regards to possible ship-to-ship interaction this must be considered as an absolute minimum and is only possible in a straight channel without any bends, at moderate speed</td>
</tr>
<tr>
<td>Topic</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Air draft allowance</td>
</tr>
<tr>
<td>Speed allowance</td>
</tr>
<tr>
<td>Aids to navigation</td>
</tr>
</tbody>
</table>

- Analysis of the research problem -
### Analysis of the research problem

<table>
<thead>
<tr>
<th>Traffic Pattern</th>
<th>Satellite-based GPS and the more accurate DGPS where a shore-based reference station within the same area corrects the GPS signal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of ship types and carried cargoes has an impact on traffic organisation as e.g. passing distances and tug escorts.</td>
<td></td>
</tr>
<tr>
<td>Hindrances through underwater works, divers and vessels have to be considered.</td>
<td></td>
</tr>
<tr>
<td>The higher the density the higher the probability of an incident.</td>
<td></td>
</tr>
<tr>
<td>Sea state</td>
<td></td>
</tr>
<tr>
<td>Wind, rain, snowfall or ice</td>
<td></td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
</tr>
<tr>
<td>In addition to the wind impact on the tracking keeping ability of a vessel, meteorological conditions may restrict visibility and require reduced speed.</td>
<td></td>
</tr>
<tr>
<td>Might also affect the water level, which would lead to a review of the traffic plan.</td>
<td></td>
</tr>
<tr>
<td>Current may either affect a vessel’s track keeping ability, when causing a drift, or influence speed over ground or both.</td>
<td></td>
</tr>
<tr>
<td>Some European waterways requiring up to 8 hours sailing time from the open sea to the port.</td>
<td></td>
</tr>
<tr>
<td>Calculation of a window which</td>
<td></td>
</tr>
<tr>
<td>Currents and Tide</td>
<td></td>
</tr>
<tr>
<td>Analysis of the research problem</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Tidal currents and heights</strong></td>
<td>makes it possible for the tide dependent vessels to navigate.</td>
</tr>
<tr>
<td>are time-dependent navigational</td>
<td>• No free flow of traffic possible</td>
</tr>
<tr>
<td>conditions.</td>
<td></td>
</tr>
<tr>
<td>• Tidal currents and heights are time-dependent navigational conditions.</td>
<td>makes it possible for the tide dependent vessels to navigate.</td>
</tr>
<tr>
<td><strong>Laws and Regulations</strong></td>
<td>• No free flow of traffic possible</td>
</tr>
<tr>
<td>• National laws have to be compatible to international law, but modifications are sometimes required</td>
<td>makes it possible for the tide dependent vessels to navigate.</td>
</tr>
<tr>
<td>• Regional/local laws cover peculiarities</td>
<td>• No free flow of traffic possible</td>
</tr>
<tr>
<td><strong>Logistics</strong></td>
<td>Ultra large container vessels, carrying almost 20,000 TEU and hence causing between 6,000 and 10,000 moves (container handlings) per terminal provide a challenge not only to the terminal logistics but also to road and rail traffic management.</td>
</tr>
<tr>
<td>• Flow of cargo to and from port and terminal.</td>
<td>ETA of such big vessels is the key trigger of all related processes far beyond mere navigation.</td>
</tr>
<tr>
<td>• Related to vessels</td>
<td>Accuracy of this information plays additionally a key role for traffic organization in tidal waterways when the waterway requires long sailing time from the open sea to the port.</td>
</tr>
<tr>
<td>• Containers are usually delivered and picked up within 3 days before arrival and departure of a vessel.</td>
<td>• ETA of such big vessels is the key trigger of all related processes far beyond mere navigation.</td>
</tr>
<tr>
<td>• Ultra large container vessels, carrying almost 20,000 TEU and hence causing between 6,000 and 10,000 moves (container handlings) per terminal provide a challenge not only to the terminal logistics but also to road and rail traffic management.</td>
<td></td>
</tr>
<tr>
<td>• ETA of such big vessels is the key trigger of all related processes far beyond mere navigation.</td>
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<tr>
<td>Accuracy of this information plays additionally a key role for traffic organization in tidal waterways when the waterway requires long sailing time from the open sea to the port.</td>
<td></td>
</tr>
</tbody>
</table>
Human Factors | The efficiency and safety of a port approach therefore also depends on the skills, the knowledge and the attitudes of the operators managing all processes from pilots conning the vessels to the mooring man, berthing it. | Education, training and experience must mirror technical and operational opportunities and risks to allow for most adequate decision-making and performance.

| Table 1: Listed influential factors on the VTM according to (Froese, 2015) |

Consequently, when planning a vessel to enter in a waterway or depart from the port towards the open sea, checking the tide window for navigation of tide-dependent vessels as well as meeting requirements from regulations such as distance between 2 vessels in a convoy, all conditions listed above in the waterway must considered, calculated and checked making it hard to manage the Vessel Traffic.\(^7\) Below illustrations provides an overview of all the components explained in this section.

\(^7\) Also cf. (Agerschou, et al., 2004), (Bichou, 2009), (Bichou, 2009), (Alderton, 2008), (Kim & Günther, 2007), (Ben-Akiva, et al., 2013), (Lemper, et al., 2012), (Froholdt & Hansen, 2011) & (Böse, 2011).
Which conclusions can be drawn? The most relevant factors for the Vessel Traffic Management as shown in Figure 2-2 determine a set of – sometimes interwoven – components affecting the navigation in longer tidal waterways that are not adjacent to the open sea. This set of – sometimes interwoven – components are affecting the navigation can be covered or classified with the help of two frameworks: Processes and Complexity.

For example, according to (Bergholz, 2009) & (Becker & Kahn, 2005) a process can be depicted as an activity which is closed or defined regarding time and content and which is necessary for the fulfilment or editing of business relevant object within an organization. 8 Considering that the whole Vessel Traffic Management constitutes an organization as well as the fact that all the different components are covered through different organizations, e.g. the shipping companies or the Hamburg Port Authority, it seems worthwhile to take a process-based perspective. Another reason for this is that extensive research has been done regarding the management and modelling of processes so that this

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8 Discussion and further definition about processes and the process management can be found in ISO 9001, ISO 9004 standards as well as in (Allwayer, 2010), (Becker & Kahn, 2005), (Nyhuis, et al., 2006) & (Zuesongdham, 2010), (Bichou, et al., 2007)
research can be based upon scientific quality standards. Additionally, with its focus on inputs, a set of value adding activities and an output, for which there is an internal or external customer, with is focus on resources regarding people, means and method and its focus on the process owner for checking or measuring the effectiveness, efficiency and continuous improvement (cf. (Bergholz, 2009)), a process-based perspective seems to fit to the outlined research question and objective. Finally, as will be shown below a process-based depiction of the entire system of the Vessel Traffic Management in longer tidal waterways is lacking in the scientific literature (cf. also the Theoretical Relevance in Section 1.3) so that an identified gap of knowledge can be dealt with.

Despite of the fact that the term complexity has become a buzzword nowadays, the entire system of components for the Vessel Traffic Management in longer tidal waterways can be characterized as complex because of the following reasons. First, several definitions about complexity fit to the outlined interwoven components of the waterway-traffic-environment-system. For example, according to (Ludwig, 2001) complexity refers to five distinctive characteristics: interconnectivity, momentum, intransparency because of confusion, intransparency because of incompleteness and uncertainties, which can all be used to depict the waterway-traffic-environment-system. Secondly, the term of complexity is often used to describe, analyse and predict the behaviour of a logistic system which is also the scope of this thesis. For example, (Meyer, 2007) defines complexity as the characteristic of a system because of its elements and its interconnections between them and how they change or evolve over time. Finally, with reference to (Mainzer, 2008) and (Froese, 2015) the following understanding can be derived: A system is complex when process multiplicity and interactivity makes it difficult to understand the input-to-output-relation. In this context, a system can also be complex for a human but not for a powerful computer that can used different algorithms and differential equations to cope with the high

\footnote{A deeper analysis and discussion of the concept of complexity can be found in (Colmorn, 2016) who based this argumentations on a wider literature review.}
amount of information and potential scenarios a system can evolve into.\textsuperscript{10} The outcome is often difficult to predict due to uncertainties, non-linearities involved but the prediction of the outcome does not always have to be meaningless due to the large uncertainty of the prediction. Therefore, the following examinations will also have to clarify the degree of complexity of the system – whether the system can behave totally chaotic and unable to predict or allows certain forms of predictions can be calculated within a certain range of errors by computer algorithms. Nevertheless, all the aspects indicate to characterise the Vessel Traffic Management as highly complex.

Consequently, it can be derived from the components and elaborated factors that are affecting the navigation in longer tidal waterways that how demanding it can be to get to the ports, which are not adjacent to the open sea so that the Vessel Traffic Management can be characterised as highly complex.

To completely define the system that is the focus of this dissertation, the next section will provide an overview of the state of the art of traffic management in general with background information about the Vessel Traffic Services, shore-based systems to support the traffic management.

\textsuperscript{10} Complicated is difficult, but reasonably safe to predict.
2.2 State of the art and current traffic organization by using the waterway-traffic-environment-system of the River Elbe

VTSs are shore-side systems provided by a shipping administration – called as competent authority – to support safe and efficient vessel movement in coastal waters (IMO 2012). The traffic image is generated from radar detection and individual vessels and their sailing plans are captured by VHF-communication, AIS and VHF direction finders exploiting VHF communication transmissions.

A VTS needs reliable and comprehensive traffic image and vessel sailing plans to provide

- information service (INS) providing traffic, weather and navigational information to support on-board decision-making delivered at regular time intervals, even-driven or upon vessel request,
- traffic organisation service (TOS), advising or, in case the VTS-operator is accordingly empowered, instructing vessels to mitigate navigational risks,
- navigational assistance service (NAS) upon request of individual vessels, by regulation, in case of extra-ordinary vessel passages (tug and tows, deep draft vessels or vessels otherwise restricted in manoeuvrability or posing a higher navigational risk) supporting the vessel command including the pilot aboard or sometimes even replacing the pilot (remote or distant pilotage) e.g. in case of adverse weather, not allowing a pilot to board a vessel,
- enforcement of laws and regulations (Froese, 2015).

An information service (INS) is always suitable for a VTS service whereas a Traffic Organization Service (TOS) and/or Navigational Assistance Service (NAS) are more advanced. According to The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (IALA, 2012) all VTS should provide INS and it is also expected that a VTS Authority can respond to a
vessel`s inquiry for a navigational assistance. It could be derived from this that a VTS should provide minimum INS and NAS with appropriately trained personnel and according to the procedures.

It is worth mentioning that there are 2 types of VTS, namely, a port VTS whose main duty is to organize the traffic entering and leaving the port to contribute to the efficiency of port related operations as well as keeping the safety as the top priority. The second type of VTS is the coastal VTS that monitors the traffic along the waterway, which is commonly been information service. Although they might offer several types of services, e.g. navigational assistance, traffic organization, according to legal framework final decision must be taken by the ship’s command. The system description in this dissertation consists of both types of VTSs.

The ports, which are not adjacent to the open sea, hardly have the capacity to allow free flow of vessel traffic. It is sometimes even not possible that the two-way traffic flow in a narrow waterway due to undesired interactions not allowed in some sections of the waterway. This calls for a stringent traffic management, which was acknowledged by the previous project and research attempts as well as expert workshops. The next sub-chapter provides brief results of these works.

Recent developments in ship sizes and increase in traffic density calls for investigating the strategic potential of VTS to plan traffic flow in restricted areas in advance. This was one of the outcomes of expert workshop held in Bremen by the Maritime Logistics Workgroup in 2009. Traffic allocation is one of the functions of the VTS and it is acknowledged in general. However, realisation stayed on distinct levels. First come, first serve rule is the commonly accepted principle to organize the traffic flow which is not necessarily seen as the optimum. The workshop concluded that there is a need for quantitative research to provide algorithms for decision support tools for VTS operators. Moreover, VTS is the authority to have the information of vessel position and voyage progress at the first place. This allows for co-operative resource planning of waterway usage, vessel support services such as pilot, tug and mooring services, clearance and supply services and transhipment operations. The
question of ‘How much time in advance should a VTS becomes involved into the vessels’ voyage plans?’ remained open.

The workshop touched on the base of improving efficiency of transport and logistics. The solution might differ due to the amount and nature of the traffic, characteristics of the fairway and existing risk factors, however, internationally agreed efficiency guidelines should be respected. Finally, it is noted that “Providing opportunities for improving the efficiency of transport and logistics” needs further investigation and calls for organisational concepts to not mix public tasks with commercial interests.

Even if we suppose that the existing infrastructure and shipping services allow safe and efficient navigation and the vessels dimensions and manoeuvrability stays within feasible margins, traffic operations must become adapted to the dynamic waterway conditions (Froese, 2015). Moreover, waterway traffic should satisfy two principles: efficiency and safety. It should be efficient in order to meet the logistics goals as well as has to be extremely safe as a collision and/or grounding bring disastrous consequences. This requires coordination of many entities, availability of reliable and consistent data and information among many other tasks to be performed, to manage the complex task of traffic management.

Additionally, a safe and efficient port call of a large vessel navigating along narrow waterways requires a cooperation of various disciplines, such as according to (Froese, 2015):

- Naval architecture regarding vessel design and hydrodynamics
- Shipbuilding
- Navigation providing manoeuvring requirements
- Hydrography capturing and describing navigable waters including tidal effects and charting it
- Hydraulics to provide knowledge of water transport
- Meteorology capturing and describing weather phenomena
Civil engineering to allow appropriate construction of shipping infrastructure

Information and communication technology providing the vital platform for information exchange and processing

Logistics providing the commercial framework of ship operation

Assistances services to provide pilotage, tugs and mooring

Shipping administrations offering vessel traffic service and establishing the regulatory framework.

Generally, the above-mentioned aspects offer to draw the conclusion to call for a holistic solution method in which the entire system is considered. This system-based approach would allow us to understand the complete problem and later to provide solutions to optimize the entire system. Therefore, the question arises if this conclusion also fits to the case of the River Elbe because it had been introduced as the exemplary subject of interest.
The Port of Hamburg can only be reached by Europe’s longest port waterway. The distance from the pilot boarding station at the mouth of the River Elbe to Hamburg is about 78 nautical miles (about 145 km). Large container vessels must match their sailing plan to the course of tide to safely navigate up and down the river. Vessels with a maximum draft of 12.80 metres can get into the river or leave the port irrespective of the tide. Using the tidal swell vessels with the draft of up to 15.10m can enter the river from the North Sea and with a maximum draft of up to 13.80m they can leave the Port of Hamburg. Therefore, for the Port of Hamburg accessibility is a sensitive issue to maintain the position as a global hub port. In order to ensure the transferability of the results, a comparison can be made with other two major and busiest ports in Europe; the Port of Rotterdam and the Port of Antwerp. In this respect, port of Rotterdam does not have problems about the accessibility with a draft allowance of 24meters (Port of Rotterdam, 2017). Port of Antwerp is located at the upper end of the tidal estuary of the Scheldt and can be navigated 80km inside. As the conditions seem more like the Port of Hamburg, a visit was made to the Port of Antwerp on the 6th of August 2014. The purpose was to investigate how the traffic flow is handled and the extent of the support from VTS to the vessels. After a very informative meeting in the VTS centre, it was concluded that a systematic approach did not exist there either. Moreover, the restriction of encounters on the River Elbe creates a special challenge which has become a more relevant accessibility problem than the tide (respectively draft) restriction. The visit to the Port of Antwerp confirmed the difficulty of the navigation along the River Elbe over other ports and made it clear that a solution to identify the capacities applicable to this area can be transferable to other regions.
Dynamics and complexity of the waterways together with the recent developments in vessel sizes makes the traffic organisation more and more complex. Traffic management should be adapted to these conditions to support efficiency and safety of navigation so that a holistic perspective is needed. In this regard, the River Elbe is the most complicated river in Europe and it can be assumed that if a solution can support the situation there it can support it everywhere so that the River Elbe also must be characterized as highly complex.
2.3 Deductions from systems engineering towards the research objectives

The introduction of a theoretical framework is needed about how or from which perspective the above-introduced research question and the subject of interest is focused on. The reason for this is that with the help of a theoretical framework the conclusions that will be drawn can be understood or more specifically reproduced in a scientific meaning. It also highlights which aspects are focused on and which are neglected.\footnote{With the help of (Schwaiger & Meyer, 2009) & (Kotzab, et al., 2005) different theoretical frameworks and research methodologies could be identified and checked about their applicability for this research.}

What is a system? The International Council on Systems Engineering (INCOSE, 2016) defines a system as being a set of integrated \textit{elements}, which can be people, processes, services, hardware, software, facilities and policies that execute a defined objective. These elements are related to each other whereby the \textit{relations} depend on the types of elements. A system is also defined by the system itself and its \textit{environment} meaning that a boundary is given that defines the in- and the outside of a system. Finally, a system can be differentiated regarding its \textit{different levels}. For example, usually the individual level of the elements is distinguished from the system level because the behaviour of the system is often different from the behaviour of the elements. In this conjunction, the Vessel Traffic Management in longer tidal waterways has been introduced as a waterway-traffic-environment-system.

The components and the environment of the system of vessel traffic can be illustrated as below, Figure 2-3. Vessels, waterway itself, the traffic, VTS centres, port authority, administration, terminals and pilots are the components of the system which regularly interact with each other. The functionality of the system is to ensure a smooth traffic organization through the River Elbe. The elements (entities) inside the boundary of the system are chosen to be interviewed. Because these entities have direct influence on fulfilling the objective of the system. Additionally, the results of the

A system-based perspective

System of vessel traffic
literature review and the expert interviews for deriving hypotheses confirmed that the waterway-traffic-environment-system is defined through these elements. Outside the boundary of the system is defined as the system environment. Regulations, weather, hinterland, shipping companies, logistics are among the elements which stay outside the boundary of the waterway-traffic-environment-system. There is an input-output relation between the components inside and outside the boundary of the system and the management or the engineering of the vessel traffic can be directly configured through the elements within the boundary.

Figure 2-3: System elements and its environment

Why to use a system-based perspective? The outcomes of a system with complicated interactions between the elements are often referred to as being complex and phenomena of complex systems comprise e.g. the bullwhip-effect, self-organization, emergence, heterogeneity that have also been identified as essential challenges for the Vessel Traffic Management in longer tidal waterways. Because of this a well-established and helpful theoretical framework becomes available for explaining the behaviour of the considered River Elbe including principles about how to derive or design conclusions for the vessel traffic management. Such principles refer to the field of Systems engineering.
The key point here is that the understanding of the system cannot be produced by the elements alone (INCOSE, 2016). Systems engineering in this context is a field of engineering which aims at creating an interdisciplinary approach to manage complex systems over their life cycles. It starts with the design of the system and continues over the life of the system. Customer needs, both business and technical, are the interests of the Systems Engineering when managing a system successfully so that the following aspects are highlighted where difficulties occur in big and complex systems:

1. Complexity management,
2. Coordination of different teams
3. Reliability
4. Logistics.\(^\text{12}\)

How to use Systems Engineering in the context of this research? The underlying idea of using this systems-based approach can be illustrated with the help of the following Figure 2-4. With reference to (Bay-Yam, 1997) it is the main idea that every system has a purpose in terms of what the system is naturally or artificially designed for. On the system level, the capability to follow this function or to find an appropriate solution should be in balance with its internal and external complexity, i.e. the requirements have to be adequately mirrored through the problem-solving capacity so that an idealized line arises. For example, the school education defines a complex system with certain requirements, e.g. the student must learn certain things. A student can be either unable to cope with the requirements so that he is below the balance. He cannot follow and does not fit to the course. On the other side, she could be very smart – even too smart – so that she is bored by what is offered.

\(^{12}\) (INCOSE, 2016; N.N., 2016; Wikipedia, 2016)
Figure 2-4: Underlying idea from Systems Theory

Inductive reasoning in the context of Systems Thinking

Besides the interdisciplinary approach to manage complex systems, understanding the complete problem before trying to find a solution is one of the main concepts of the systems thinking concept.13 A scientific approach should be general and applicable for all areas. This means applying the methodology of ‘deductive reasoning’ which can also be called top-down logic. However, each individual area has many alternatives and when it is investigated from a general approach the entire system explodes with little chance to provide solutions. Additionally, real-life experiences show that a combination of top-down and bottom-up is almost always needed to meet design requirements in an effective way. For example, when working bottom-up one needs to understand the terms of reference which is part of top-down and during the whole design process bottom-up steps need to become adjusted to the goals and vice versa. Bearing this in mind and by because one has to start the opposite methodology as introduced above, inductive

13 Cf. (Gharajedaghi, 2006)

Concluding task

Therewith one main task will comprise the positioning of the problem-solving capacity of the current organization of the Vessel Traffic Management regarding the external requirements in terms of the complexities of the system.
reasoning, will be approached (first) because it also fits to the systems engineering approach: capturing all relevant conditions and governing factors to understand the problem as a whole. Therefore, e.g. data collection techniques through interviews are carried out with the bottom-up logic which requires the selection of a topic of interest to capture all governing factors in a traffic management.

How to summarize the findings of this Chapter and which conclusions can be derived towards the research objectives by following the system-based approach?

Port approaches that are not adjacent to the open sea resulting in longer tidal waterways to be navigated very seldom the capacity to allow for free flow of vessel traffic because there are sections of waterways where large ships may neither overtake nor encounter each other so that some narrow waterways – including the River Elbe – only allow for one-way traffic or provide encountering and overtaking “boxes” in wider sections. This calls for a stringent traffic management providing sailing plans to vessels and guide them accordingly, continuously tracking position and speed, intervening once pre-planning traffic pattern is not maintained. Hence it has been shown that such a Vessel Traffic Management can be characterised as highly complex because the factors of vessel, waterways, traffic, weather, current and tide, laws and regulations, logistics and human factors constitute a complicated set of intermingled components of the waterway-traffic-environment-system.

In this regard, it was also concluded that the traffic management must adapt to these dynamic and complex conditions in order to support efficiency and safety of navigation. For this, the current traffic organization was introduced namely in the form of Vessel Traffic Services and its different components. Despite of these services, there is still a navigational principle reading “first come, first serve”, a reluctance of shipping authorities to intervene with the sequence and no satisfactory tools to pre-plan and manage such complex traffic conditions. A time ago, even a long waterway was
easy to manage if there were only very few big ships per high tide to consider. Encounterings and overtakings could be managed on short notice either by the vessels commands alone or assisted by the vessel traffic service. But since the number of large vessels meanwhile increased dramatically and is further increasing – which is also the case for the River Elbe – it is shown that the optimum flow of traffic is difficult to determine, and that current approach lacks a holistic approach in which all relevant factors are considered. Because of this an optimization goal must be the total throughput of traffic not the easiness of an individual vessel. This can of course result in waiting times for some vessels. This optimization goal for optimizing the total throughput of traffic instead of optimizing the situation of individual vessels pointed to a system-based underlying theoretical framework because the differentiation between an individual level of elements and the level of the entire system is an essential feature for which different phenomena were introduced. The research objective then is to develop a model, allowing for computer-based traffic prediction and management and to support decision-making within a system of increasing complexity.
Figure 2-5: Conclusions for the research objective

Because of the identified gaps of knowledge, the research objective is set to develop a generic model that can serve as the basis for a computer-based traffic prediction and management for the support of decision-making within a system of increasing complexity.
3 Empirical data collection through expert interviews

This Chapter focuses on the empirical data collection through field or expert interviews and is subdivided in three sections as shown in Figure 3-1.

Figure 3-1: Overview Chapter 3

- **Section 3.1**: Concept and design of the research methodology for the empirical data collection
- **Section 3.2**: Results of the expert interviews and workshops
- **Section 3.3**: Deduction of findings towards the research objectives
3.1 Concept and design of the research methodology for the empirical data collection

The result of the elaboration of the research problem was to an analytical approach that can serve as a basis for a computer-based traffic prediction and management to support decision-making within a waterway-traffic-environment-system of increased complexity. Against the background of the identified gaps of knowledge concerning empirical information about the Vessel Traffic Management in longer tidal waterways, empirical information has to be collected. Regarding the research methodologies, qualitative methods are usually distinguished from quantitative ones. Both can have either the nature of generating or proving hypotheses (cf. Figure 3-2). Due to the characteristics of this thesis, a qualitative research approach was selected. This is because before a quantitative analysis or even a simulation can be achieved, one should first close the gap of lacking cause-and-effect-relations. In the field of qualitative research there are many different types of data collection methods. Interviews (with experts) are one of them. They are selected when a deeper understanding of the phenomena is sought for. Moreover, the aim is to explore the views and experiences of the individuals. \(^\text{14}\) The above-mentioned project results and previous considerations about the state of the art contributed to define the research question in terms of preparing the interviews. Some hypotheses about traffic management before carrying out the interviews were defined. Some new issues came up during the interviews, which allow deriving some additional assumptions. Therefore, the expert interviews as the selected method for the data collected have to be characterized as hypothesis-generating and hypothesis-confirming.

\(^{14}\) (Gill, Stewart, Treasure, & Chadwick, 2008).
Empirical data collection through expert interviews

Figure 3-2: Research methodologies for the data collection


Conclusions

Therefore, expert interviews are selected as the research methodology for the empirical data collection comprising hypothesis generating and confirming aspects.

Design

What was the design of the expert interviews? After making the decision to go for expert interviews for bridging the gap of a lack of information, a concept about how to run the interviews have to be generated. For this, questions about the concept including the underlying assumptions, different types of interviews (and which one to select), about type of participants and phases focussing on different goals, needed to be answered first.

Concept

As already mentioned, interview outcomes were expected to reflect the state of the art of traffic management in a longer tidal waterway, which should lead to understanding the system, its complexities and the underlying problems. This would at the same time lead to the identification of the possible ways to optimize the traffic flow for the whole river.

Interview types

Types of interviews can be differentiated according to three forms, namely structured, semi-structured or unstructured (Legard, 2003) (Ritchie, 2003):

- **Structured**: Pre-determined questions with almost no variation. They do not allow some space for some follow up questions. They are easy to administer; however, they do not provide deeper understanding.
- **Semi-structured**: It includes some key questions about the topic and allows both interviewer and interviewee to dive into details of specific areas. It is more flexible than the structured interviews and allows bringing up issues that were not considered before.

- **Unstructured**: As a contrary to the structured interviews unstructured interviews open the conversation with an opening question and do not follow a pre-defined structure. It takes quite a lot of time and it might be difficult for the interviewee to participate in due to lack of structure. They are usually preferred when there is almost nothing known about the subject of interest.

The semi-structured interviews were chosen to be used to investigate and capture the conditions, which are governing the difficulties of traffic management in a longer tidal waterway. The reason for this was because it allowed the participants to provide information about the traffic management within a structure, which is achieved through some questions prepared in advance and background information provided, as well as it gave freedom to them to express more about some details that might not have been considered.

At first, individual expert interviews, which are characterised as hypotheses-generating nature towards the research objectives, will be conducted. The aim is to close a gap of knowledge towards empirical information by using the case of the River Elbe. The findings of these interviews, which will be presented in section 3.3 and 3.4, will serve as an input towards the procedural model.

After the individual interviews, the interviewees and some other industry relevant partners will be invited to a workshop. In science, focus groups can in science be used as a stand-alone method as well as being complementary to a previous method. Discussions, interaction of the participants and mixture of attendees play a key role in the results of the data collection (Kitzinger, 1994), (Stewart, 1990). This comprises the second phase, because this dissertation is organized to receive feedback from the interview participants about the outcomes of the interviews, thus it may be characterized Two phases
as hypothesis-confirming. Moreover, it will help to clarify, extend and increase the quality of the information collected through the interviews. Finally, the process diagrams – to be introduced in Chapter 4 – will be discussed with the group to get their validation. The selected focus group will be mainly the interviewees who are the entities of the system. They have had already a formal relationship among each other. Other attendees will also be familiar to the topic as well as the system participants, because they have been in contact previously due to a project or another research activity. The logical relations of these various aspects are illustrated in Figure 3-3.

Figure 3-3: Logical relations of the phases of the interviews

The answer to the question about who and why they should participate in the expert interviews is, on the side, the result of the logical considerations explained before on the one side and of their time availability, on the other side. Finally, there is a reason for a gap of empirical information, because such expert interviews are always intensive regarding time and resources. Additionally, it was outlined that all the different actors in the considered system are more focussing on their own interests so that they must be convinced to share basic and sometimes business or safety sensitive information for the sake of reaching a long-term goal. Nevertheless, at the end it was successful to interview eight different entities varying from port authority, administrations, pilots and private
stakeholders, for the exemplary subject of interest of the River Elbe. Therewith, it is possible to achieve a comprehensive, extensive and representative picture of the River Elbe by asking those actors from operative to business level. The entities and explanation why they were asked or what was their special focus are summarized in Table 2.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Interview 1</td>
<td>Head of Elbe pilots</td>
<td>20/02/15</td>
<td>Hamburg</td>
<td>Pilots face the complexity and challenges of waterways directly onboard the vessels. They experience the interaction between vessels and waterway at the first place.</td>
</tr>
<tr>
<td>Interview 2</td>
<td>Harbour Master</td>
<td>12/03/15</td>
<td>Hamburg</td>
<td>Port authority should have the whole overview on the waterway and plays an important function in planning.</td>
</tr>
<tr>
<td>Interview 3</td>
<td>3 pilots</td>
<td>20/05/15</td>
<td>Cuxhaven pilot vessel</td>
<td>Cuxhaven is the entrance to River Elbe that means the 1st ETA point, which triggers all the processes coming ahead.</td>
</tr>
<tr>
<td>Interview 4</td>
<td>Head of operations  +</td>
<td>5/06/15</td>
<td>Hamburg</td>
<td>Terminal availability and planning is one the</td>
</tr>
</tbody>
</table>
- Empirical data collection through expert interviews -

<table>
<thead>
<tr>
<th>Interview</th>
<th>Department</th>
<th>Date</th>
<th>Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Operations</td>
<td>24/06/15</td>
<td>Hamburg</td>
<td>This interview is carried out in VTS Hamburg in order to see on site how VTS is involved and which technology is used for information handling.</td>
</tr>
<tr>
<td>6</td>
<td>VTS</td>
<td>29/06/15</td>
<td>Hamburg</td>
<td>Harbour area has its special conditions, i.e. turning the vessels within the tide window, other traffic around the port area. Therefore, experiences from them are important.</td>
</tr>
<tr>
<td>7</td>
<td>VTS</td>
<td>03/07/15</td>
<td>Brunsbüttel</td>
<td>Brunsbüttel VTS is responsible for the area in River Elbe where encountering restrictions exist.</td>
</tr>
<tr>
<td>8</td>
<td>WSA</td>
<td>18/08/15</td>
<td>Hamburg</td>
<td>It is aimed at learning more about the calculations of tide windows and planning perspectives.</td>
</tr>
</tbody>
</table>
Interview 9  
Agent: Ship Agent  
Date: 25/02/2016  
Method: Via email  
Agents play an important role in providing important information about the vessels 'arrival and departure.

Table 2: Overview of the expert interviews

Interviews were opened with general background information about the aim of the research and the thesis. Questions related to each entity, for instance their tasks, how they conduct these tasks, interaction with other involved entities, type of information that is exchanged among them and specifications of all these were asked in order to understand the actors, their roles and interactions. Further and individual questions to each entity rose from the conversation itself, which brought up some issues that were not considered before. Some of the interviewees were contacted via email later, at the transcription/summarizing phase, in order to clarify some points from the interviews. The questions or points that remained open/unclear were asked during the expert workshop. The workshop was opened with a presentation on the brief general refreshing information, followed by the summary of interviews and the outcomes from them, including process diagrams. These diagrams were explained and analysed together with the participants, which allowed for update and validation on them.

Consequently, by answering essential questions about the concept, the type, the execution and the participants (including the reasons), the design of the expert interviews could be successfully implemented towards the goal to understand the system, its complexities and the underlying problems from a system-based perspective.
3.2 Results of the expert interviews and workshops

The interviews – their complete transcripts can be found in the Appendix – provided a lot of information about the traffic management of one of the most difficult waterways in Europe. In order to be able to present the results in a structured way, systems engineering elements are taken as the main categories. Complexity management, information, communication, reliability, logistics and coordination of different teams are the areas where complex and big systems have difficulties (cf. Chapter 2).

1. Communication: It has been one of the most touched issues during the interviews. It includes, the ways of communication and the type and content of the information provided. Information is categorized with the reliability on the following point below. Regarding communication, the following statements are the main outcomes.

   a. Too much communication takes place with too many entities in order to get one vessel in.
   b. There are communication difficulties in some areas that end up sending one request or one question to more than 2 entities.
   c. Estimated Time of Arrival is mostly received from the agents. Depending on the available time, it is reported either by phone or email.
   d. When the vessel approaches, the river master contacts the VTS centre and pilots via VHF to announce the ETA, which might differ from the one from the Agents.

2. Information - Reliability: ETA and ETD are the crucial information that is needed for the planning of the traffic flow. Moreover, the draft of the vessels as well as the air draught depending on the terminal location, are necessary to be known for the tide dependent vessels. The main dimensions of the vessels such
as length and beam remain unchanged regardless from
loading/discharging.

a. Information pool (PRISE) is not used by all the actors involved
in the system (6/8). Many accept that it is a nice tool,
however, they say that they wouldn’t rely on it due to not
being sure of the accuracy of the information. Not all
vessels/terminals are connected to this system.
b. The most reliable information is taken from Port VTS by
different means of communication, e.g. fax and telephone
(7/8).
c. In addition to safety, easiness of operation is an important
element of the traffic flow. However, as the density of traffic
has been increasing over the years, there is now more
communications with more information flows.

3. Logistics: Logistics refers to the activities carried out to
prepare for and execute the traffic management in a waterway-
traffic-environment system.

a. According to the international and national law, when the river
is free, the incoming vessels should be let in.
b. For the tide dependent vessels, the following factors are taken
into consideration: tide window at the both ends of the river,
distance to be left between 2 ships and meeting restrictions.
With these factors in mind, the system is tried to fit in as many
ships as possible.
c. It is noted that there is no support system to provide a number
and sequence of the vessels (4/8). The system works flexible
for the moment with the aim of getting in as many vessels as
possible. As it is not known, how the vessels are planned
terminal-wise, it is not preferred to dictate which vessel to get
in and how to queue them. The reason is due to the distinction
between commercial and nautical decisions.
d. On a voluntary basis, some shipping companies are contacted
in advance via agent in order to inform them about allowed
time of arrival (ATA) (3/8). It is done in the cases of e.g. not
Empirical data collection through expert interviews

sufficient increase in the water level at the time of planned arrival and/or no berth available. The main aim is to receive a positive feedback of shipping lines that the port is reliable in terms of providing early and accurate information as well as efficient and safe.

e. The latest statistics (based on Interview 8) show that the number of tide dependent vessels is less than the number of vessels with a wide beam which causes encountering problems in some sections of the waterway (4/8).

4. Coordination of different teams: Due to geographical, legal and operational reasons, different actors are responsible for the decision-making and information provision among many other processes during a vessel’s passage.

a. There are many decision-making authorities. This creates more complexity in coordination of the actions.

b. It is added that 100% participation of all entities in the system, in terms of information provision and exchange, is crucial; otherwise it will not have a positive impact on the optimization goal. The Port VTS acts voluntarily as a moderator between terminals and the rest of the entities in the system. Planning is initiated from the Port and followed by checking it with the other VTS areas against any conflicts.

c. Last minute changes occur quite often. The question of how to make all the parties aware of the need for a stricter system stays open.

5. Complexity management: Complexity management deals with the elements of systems engineering, such as processes, organization and IT systems. It aims at analyzing these elements to identify the optimization potential. In this regard, it generally aims at reducing the number of alternatives. Compared to, for example the manufacturing of a car, where alternatives are provided with minimum effort. In principle, it covers, as what has been mentioned
in the above points, i.e. information exchange, communication, coordination and logistics.

a. There are processes that are mandatory and standard. However, there are also activities, sometimes taking place, depending on the situation, that increase the complexity and require a system-based approach.
b. There are many decision-making authorities.
c. Nautical vs. commercial interests should be moderated and better managed.

Consequently, the content of the empirical expert interviews is analysed from a Systems Engineering based perspective. As the next step, the conclusions towards the research objectives will be drawn.
3.3 Deduction of findings towards the research objectives

Deductions

The expert interviews allow the following deduction of findings towards the research objectives.

1. The expert interviews confirmed the complexity of the state-of-the-art of the traffic management.
2. There are many entities involved in the decision-making. This is expressed inevitable due to
   - Legal structure (e.g. different federal states coverage, rules and regulations and responsible parties)
   - Technical – navigational coordination (e.g. limits of the waterway, dynamic and static characteristics of the vessels and waterway)
   - Commercial coordination (e.g. shipping lines and terminals relationship, tug companies and number of available tugs, especially for big vessels and trying to keep the pace with the economy)
3. All these entities seem, according to the interviews, interdependent and play important roles in making the traffic management work.
4. Each entity carries a different type of responsibility in the system. Thus, they do not intervene with each other's interests, i.e. commercial vs. nautical. On the other hand, interviews confirmed the latest changes in the traffic density and the vessel sizes that the number of large vessels (330m length and 45m beam and above) increased in the last 6 years up to 60%. The port of Hamburg was called by 972 of these vessels in 2014. The plan of future ship orders show that it will additionally increase in the next 2 years up to 40%. This calls for a stricter system. Both the technical part of the traffic management (PPU, radars etc.) as well as the information flow have to be adapted in advance to this change.
5. Decision-making should be clearer despite the number of entities involved. All the processes should be transparent so
that everybody can follow the planning. Traffic management on case-by-case basis has the risk to hinder seeing the full picture.

6. In addition to the **safety** to be ensured in the traffic flow, **easiness** is one of the pillars of the traffic management. It is explained that the traffic can flow without restrictions and with less communication possible in order to avoid overflow of information. However, as the density of traffic has been already increased in the last years, it is confirmed that there have been naturally more communications taking place than before. It is noted that a vessel can hardly complete her passage, without influencing and/or being influenced by another vessel(s). Therefore, necessary information should be there to get a complete picture for all involved entities.

7. It is deducted from the interview outcomes that to achieve a better coordination of different entities and further ensure the easiness and efficiency of the traffic flow, the necessary information should be:
   - Available on time (timeliness of the information)
   - Reliable
   - Consistent
   - Comprehensive
   - Up-to-date and valid.

8. Increasing the awareness to share information naturally, not only upon request, is one of the points mentioned during the interviews. This has been improved in the last years. There is however still some space for further improvements.

9. To achieve a system based approach and then step forward to optimize the system, 100% participation of all entities, e.g. in the data provision, is necessary.

10. Departure schedules of the vessels are important to make the planning in advance.

11. Statistics show that the number of tide dependent vessels is less than the number of vessels with a wide beam, which causes encountering problems more in sections of the waterway.
12. Finally, it can be concluded that the current communication is too complex, because too many and too different elements are communicating within the system.

Restrictions

Additionally, the expert interviews point out the following facts and restrictions about the River Elbe.

1. From Cuxhaven to Hamburg, it is 70 nautical miles in distance. A pilot change takes place at Brunsbüttel and from Brunsbüttel to Hamburg, it is 36 nautical miles.

2. At high tide with the current, it takes around 6 hours to Hamburg from Cuxhaven and against the current about 7 hours.

3. Extraordinary big vessels are defined as vessels that are either 330m or more in length or 45m or more in beam.

4. The weather limit is defined in steps for the vessels from 330m in length and above. For instance, for a 400m long vessel, it is Bft6 the limit to navigate in the river.

5. There is no regulated speed to be followed through the river. Masters must take care of not to damage anything. There are some proposals of speed values to be followed in different areas, namely 15kts between Cuxhaven and Brunsbüttel, 14kts further to Glückstadt and 12kts to Wedel. As the port has a dense traffic, 10kts is the recommended speed for the port area.

6. From open sea to buoy number 74 (Störmündung – aka Stör) encountering is possible. Between buoy 74 to buoy 125 (Tinsdal) encountering is not allowed with an added of 90m and above. In front of Pagensand there is a stretch of 3.5 nm, where encountering is possible up to 92m added beam, however, this is not an official regulation. When necessary, in discussion with VTS centres, pilots on board and Master, Port VTS can give an exemption of 92m added beam encountering.

7. Vessels leave the port at the low tide in order to meet the high tide between Glückstadt and Brunsbüttel.
8. From open sea to buoy number 74 encountering is possible. Between buoy 74 (Störmündung) to buoy 125 (Tinsdal) encountering is not allowed with an added of 90m and above. In front of Pagensand there is a stretch of 3.5 nm where encountering is possible.

9. Finkenwerder and E1 racon buoy are used as reference points. Outgoing vessels should pass already Finkenwerder before the incoming vessels can enter the river – pass E1 racon buoy. This avoids encountering of two vessels with an added beam of 90m and above and valid for not tide-dependent vessels. In the case of tide dependency, incoming vessels can enter the river approximately 1hr / 1hr 15min later than the passage time of Finkenwerder of the departing vessel.

10. Allowed Under Keel Clearance (UKC) is laid down in the fairway adaption plan, which is in practice 50cm.

11. For a maximum draft of 15.10m incoming vessel, there is a tide window of 20 minutes, where she needs to pass Vogelsand Lighthouse (Buoy 14). One can fit 2 vessels within this tide window, one at the beginning and one in the end. There will be a 20-min distance between them.

12. There is a reference vessel (Bemessungsschiff) according to whom all the calculations are made. This vessel has the dimensions of L: 350m, B: 46m, D: 14,5m. According to this vessel the tidal window is 2 hours; 4 of these vessels can depart within these 2 hours. That means that, they have 40min distance between each other. When the draft increases the tidal window decreases. For the outgoing vessels, draft of more than 14,5m (sea water)/14,8m (fresh water) is not allowed. For the incoming vessels, it is allowed more as they are navigating with the tidal current.

13. It is recommended to leave 2 nautical miles between two vessels, although in practice it is calculated as above mentioned, according to reference vessel.

14. At maximum 4 of maximum size container vessels can be turned at the harbour area in different turning circles.
15. Each terminal has its own tide restriction and respective arriving and departing times. The table from NTK is in appendix. Tide restrictions for each terminal.

16. Air Draught (AD) restriction for mainly Altenwerder terminal. The bridge needs to be passed at low tide whereas Schulau (the shallow water area between Hamburg and Brunsbüttel) needs to be passed at the high tide.

17. During low water, the AD should be 54,9m. When a vessel first time calls Hamburg, the owner is asked for the total height of the vessel and AD is calculated from the actual draught. Additionally, Cuxhaven VTS asks the AD of the vessel, when she is approaching the River Elbe. And, she was asked by the port, when she enters the port limits.

18. Quantification of current: Ebb current averages 2kts, flood 2,5kts. In front of Brunsbüttel Elbe port currents are 3-4kts. Around Cuxhaven it can go up to 5kts, when navigated close to Amerikahafen.

19. For the extraordinarily big vessels, there is no possibility to anchor in the river. There is a plan to build a dolphin around Brunsbüttel in the future.

20. Terminals CTB (Container Terminal Burchardkai) and Eurogate need to top-up their cranes when there is a big vessel passing by.

Aggregation

How can these results be aggregated towards the research objectives? The above introduced deductions support the conclusion that the system must be characterized as highly complex regarding its dynamics and its structure as well as its flow of information. Because of this, it can be better understood why the actors often try to optimize their own benefits, which does not necessarily lead to an effective or efficient behaviour of the entire system e.g. in terms of navigational risks or economic feasibility. On the other side, in terms of the problem-solving capacity of the system (cf. section 2.4), the organisational complexity must be characterized as low, because due to all the local optimizations, the problem-solving capacity does
not fit to deal with a system-wide optimization. Therefore, by considering the idealized line for the optimization, in which the problem-solving capacity is in balance with the complex requirements of the system, it can be deduced, as illustrated in Figure 3-4, that the organisation of the Vessel Traffic Management needs an improvement to cope with all the requirements. As result, the need to understand and analyse how the current Traffic Management is organized is needed.

**Figure 3-4: Illustration of the underlying theoretical framework**

The expert interviews pointing to the conclusion that an overarching comprehensive system that is consistent and reliable is needed, because of the decentralized decision-making processes against the background of a high informational, dynamic and structural complexity. To make the ports that are not adjacent to open sea more reliable, information must be accurate and provided in time as well as a safe and efficient passage must be ensured.
4 Process modelling

Overview Chapter 4

One essential result of the empirical data collection through field interviews showed that a holistic representation against the background of the systems thinking approach is needed. Such a holistic representation, i.e. a model, is the basic condition for the development of a computer-based program towards the optimization and the decision-making of the Vessel Traffic Management in longer tidal waterways. Therefore, research methodology of the process modelling will be firstly introduced (section 4.1), then the results of the process modelling will be introduced (section 4.2). At the end of this Chapter findings towards the research objective will be deduced (cf. Figure 4-1).

Figure 4-1: Overview Chapter 4
4.1 Concept and idea of the research methodology of the process modelling

The research methodology of the process modelling – sometimes also referred to as the business process modelling – comprises the abstract and often graphical representation of repeating activities in a defined business. This modelling approach is therefore an abstract representation of the reality to describe and analyse the logical relations and the development, i.e. the process, of the flow of information or goods etc. between different organisational units. With reference to (Zuesongdham, 2010) who evaluated the different process modelling techniques with the help of 20 criteria the so-called Business Process Modelling (BPM) is used because it best fits to meet the requirements for an application in the context of the field of maritime logistics. (Zuesongdham, 2010) summarizes the technique based on a literature review as a “method to represent the process in an illustrious way either by using diagrams, flowcharts or other techniques as a description or explanation of what the process looks like, which information it contains and how it links to other process” (Zuesongdham, 2010, p. 14). Therewith the methodology usually aims at enabling and exploiting general knowledge for reengineering projects that also fits to the idea of Systems Engineering. With reference to (Allweyer, 2010) the BPM approach comprises a wide set of symbols, aka Business Process Modelling Notation (BPMN). Figure 4-2 illustrates only the main components. The processes or the activities that repeatedly occur are depicted through rectangles that can comprise different sub-processes indicated through small boxes with the plus-symbol. To define the event or potential important parts in-between circles are used to define so-called events. To mirror the essential logical relations between the activities that relate to each other through lines so-called gateways are used and illustrated through diamonds.

15 Introductions into the field of the process modelling that also served as the baseline to summarize the idea of this research methodology can be found in (Allweyer, 2010; Arndt, 2010; Becker, Kugeler, & Rosemann, 2005; Nils Hagen, 2006; Höbig, 2006; Zuesongdham, 2010). Regarding the process management and modelling also cf. the ISO 9001 and 9004 standards that also contain information regarding process management and modelling as well as the introduction in section 2.1.
Hereby different logical relations can be distinguished. For example, the “+”-symbol represents that both processes take part (“and”) while an “x” serves to indicate an or-relation. Further gateway-symbols are in use and can be found e.g. in (Allweyer, 2010).

Figure 4-2: Introduction of the business process modelling

Therefore, it is the aim to cover the entire system within the framework of the business process modelling because it fits to the requirements from the field of maritime logistics and enables to reflect the logical relations between the elements of the entire system (elements and relations).
### 4.2 Results of the process modelling – descriptions and diagrams of the incoming and outgoing traffic processes

The results of the process modelling for the current status quo are separated into a description for the incoming and for the outgoing processes that are summarized in Table 3 and Table 4. Based on these two descriptions two entity-relationship diagrams could be drawn as shown in Figure 4-3 and Figure 4-4. Table 3 and Table 4 are also shown in the Appendix in Table 5 and Table 6 where additional information about the functions are included.

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
<th>Performer</th>
<th>Remark</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Gather ETA</td>
<td>Hamburg VTS/Port VTS</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>ETA is entered into PRISE</td>
<td>Terminal that have access to PRISE</td>
<td>Port and pilots have access to this list as well</td>
</tr>
<tr>
<td>1.2</td>
<td>ETA of all vessels collected by the IT system of the port</td>
<td>This is the first official channel to gather the ETA. Port has its own IT system, which gathers ETA through radar and AIS signals, that is also accessed by all VTS centres. This</td>
<td>Hamburg VTS/Port VTS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>creates one of two official lists of ETA</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>----------------------------------------</td>
<td>---</td>
</tr>
<tr>
<td>1.3</td>
<td>Vessel provides ETA to river pilots 36/24/12/6 hrs in advance</td>
<td>Via email in order to be able to get a pilot on arrival</td>
<td>Vessel</td>
</tr>
<tr>
<td>1.4</td>
<td>ETA is sent by the agent via email or phone 24hrs in advance</td>
<td>This is the second official channel to gather the ETA</td>
<td>Agent</td>
</tr>
<tr>
<td>2</td>
<td>Generate the list of vessels with 30 and 40m and above in beam</td>
<td>The ETA of all vessels arriving are collected from various sources and a special list for the big vessels are generated</td>
<td>Hamburg VTS/Port VTS</td>
</tr>
<tr>
<td>3</td>
<td>Send the list to the pilots and other VTS centres</td>
<td>The ETA list of vessels with a beam of 30 and 40m and above is sent by fax to pilots</td>
<td>Hamburg VTS/Port VTS</td>
</tr>
<tr>
<td></td>
<td>Process modelling</td>
<td>and other VTS centres</td>
<td>do their planning</td>
</tr>
<tr>
<td>---</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>4</td>
<td>Prepare the plan of arriving departing and passing vessels for the next tide</td>
<td>Mainly Cuxhaven VTS plans for the arriving vessels, Brunsbüttel for the passing and Hamburg for the departing vessels.</td>
<td>Vessels might not necessarily have draft restriction but the meeting restriction due to beam. Or both restrictions might take place.</td>
</tr>
<tr>
<td>5</td>
<td>Is the vessel tide dependent?</td>
<td>Cuxhaven VTS is responsible for the planning of tide dependent arriving vessels</td>
<td>Cuxhaven VTS</td>
</tr>
<tr>
<td>5.1</td>
<td>Check the next tide window and the water level prognoses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1.1</td>
<td>Is the water level expected to increase sufficiently?</td>
<td>All VTS centres have to confirm an increasing tendency in the</td>
<td>All VTS centres</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

63
<table>
<thead>
<tr>
<th>Water level gauges</th>
</tr>
</thead>
</table>

| 5.2 | Is the berth free? | Big container vessels have guaranteed berth within a specific time and tide limits. In case any delay occurs from incoming and/or outgoing side, it is necessary to check it again | Cuxhaven VTS asks Hamburg VTS | If yes, go to 5.2.1, if no go to 5.2.2. |

| 5.2.1 | Vessel enters | Cuxhaven VTS |

| 5.2.2 | Wait outside for a free berth and the next tide | When the berth is not free the tide dependent vessel will miss the tide window. | Cuxhaven + Hamburg VTS |

| 6 | Is there any vessel ready to depart? | Although the plans are made in advance for arrival and departure, due to last minute changes and considering the time to navigate the | Cuxhaven + Hamburg VTS | If yes, go to 6.1, if no, go to 6.2. |
river for an incoming vessel, it might occur that another vessel announce her departure after the incoming vessel entered.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6.1</strong></td>
<td>Is the added beam $\geq 90m$?</td>
<td>Brunsbüttel VTS</td>
</tr>
<tr>
<td></td>
<td>If yes, go to 6.1.1, if no, go to 6.2.</td>
<td></td>
</tr>
<tr>
<td><strong>6.1.1</strong></td>
<td>Is the meeting position of 2 vessels above Stör?</td>
<td>Brunsbüttel VTS</td>
</tr>
<tr>
<td></td>
<td>If yes, go to 6.1.2, if no, go to 6.2.</td>
<td></td>
</tr>
<tr>
<td><strong>6.1.2</strong></td>
<td>Avoid encountering in the restricted area</td>
<td>Brunsbüttel VTS</td>
</tr>
<tr>
<td><strong>6.1.3</strong></td>
<td>Advise the vessel to adjust speed and arrange them meet outside the restricted area</td>
<td>Brunsbüttel VTS</td>
</tr>
<tr>
<td><strong>6.2</strong></td>
<td>Vessel enters, and</td>
<td>Cuxhaven + Hamburg VTS</td>
</tr>
<tr>
<td></td>
<td>Process ends.</td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td>Description</td>
<td>Performer</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Send ETD 2 hrs before departure - 4 hrs before departure for the big vessels - to the harbour</td>
<td>Agent</td>
</tr>
<tr>
<td>2</td>
<td>Send ETDs to Port VTS via computer</td>
<td>Harbour pilots</td>
</tr>
<tr>
<td>3</td>
<td>For the big vessels calculate the time of passing Finkenwerd</td>
<td>Hamburg VTS/Port VTS</td>
</tr>
</tbody>
</table>

Table 3: Incoming traffic process description
- Process modelling -

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Process</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Can the vessel depart?</td>
<td></td>
<td>Two questions to be asked at this point to confirm the passage – follow 4.1 and 4.2 and their sub-processes</td>
</tr>
<tr>
<td>4.1</td>
<td>Is there an incoming vessel in the river already?</td>
<td>Although the plans are made in advance for arrival and departure, due to last minute changes and considering the time to navigate the river for an incoming vessel, it</td>
<td></td>
</tr>
</tbody>
</table>

**Procedure**

- Vessel information is faxed to VTS Brunsbüttel.
- The procedure is that the passing time of Finkenwerder of the departing vessel is given to the incoming vessel as passing time of E1 buoy.
- Vessel can depart?
- Brunsbüttel VTS in communication with other VTSs.
- Two questions to be asked at this point to confirm the passage – follow 4.1 and 4.2 and their sub-processes.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1</td>
<td>If yes, go to 4.1.1,</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>If no, go to 4.2</td>
<td></td>
</tr>
</tbody>
</table>
might occur that another vessel announce her departure after the incoming vessel entered.

<table>
<thead>
<tr>
<th>4.1.1</th>
<th>Is the added beam &gt;= 90m</th>
<th>The beams of 2 encountering vessels are added simply together and if the result is &gt;= 90m, there are restrictions for encountering</th>
<th>Cuxhaven VTS + Hamburg VTS/Port VTS</th>
<th>If yes, go to 4.1.2, if no, go to 4.2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.2</td>
<td>Is the meeting position above the Stör?</td>
<td>Above the Stör river is restricted for encountering of vessels with an added beam &gt;= 90m (see process 4.1.1)</td>
<td>Brunsbüttel VTS</td>
<td>If yes, go to 4.1.3, if no, go to 5</td>
</tr>
<tr>
<td>4.1. 3</td>
<td>Avoid encountering within the restricted area</td>
<td>It is done via the process 4.1.4</td>
<td>Brunsbüttel VTS</td>
<td></td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
<td></td>
</tr>
<tr>
<td>4.1. 4</td>
<td>Advise the vessel to adjust speed and arrange them to meet outside the restricted area</td>
<td></td>
<td>Brunsbüttel VTS</td>
<td>Process ends</td>
</tr>
<tr>
<td>4.2</td>
<td>Is the vessel tide dependent?</td>
<td>Brunsbüttel VTS + Hamburg VTS/Port VTS</td>
<td>If yes, go to 4.2.1, if no, go to 4.2.2</td>
<td></td>
</tr>
<tr>
<td>4.2. 1</td>
<td>All sectors check the water level gauges</td>
<td>All VTS centres have to confirm an increasing tendency in the water level gauges</td>
<td>All VTS centres</td>
<td>Whether the water level is increasing or not is to be asked at the process 6</td>
</tr>
<tr>
<td>4.2. 2</td>
<td>Provide the given Finkenwerder passage time of the outgoing</td>
<td>Cuxhaven VTS + Brunsbüttel VTS</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>vessel as the entrance time of incoming vessel of any size</strong> <em>(Time of passing Elbe 1 buoy)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>Vessel departs, and it is monitored.</td>
<td>All VTS centres</td>
<td>Process ends.</td>
<td></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td>Is water level increasing in all areas?</td>
<td>All VTS centres</td>
<td>If yes, go to 6.1, if no go to 6.2.1/6.2.2/6.2.3</td>
<td></td>
</tr>
<tr>
<td><strong>6.1</strong></td>
<td>Calculate the earliest and latest passage time of Schulau</td>
<td>Schulau is the point where the vessels need to pass at the high-water due to insufficient depth there.</td>
<td>Brunsbüttel VTS</td>
<td>Proceed to process 8</td>
</tr>
<tr>
<td><strong>6.2.1</strong></td>
<td>Can the vessel discharge ballast?</td>
<td>Vessel/Terminal</td>
<td>If yes, go to 6.1, if no, go to 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Process modelling</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2.2</td>
<td>Can the vessel cut and go earlier?</td>
<td>Vessel/Terminal</td>
<td>If yes, go to 6.1, if no, go to 7</td>
<td></td>
</tr>
<tr>
<td>6.2.3</td>
<td>Can the vessel remove some cargo</td>
<td>Vessel/Terminal</td>
<td>If yes, go to 6.1, if no, go to 7</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Do not allow departure / Wait for the next tide</td>
<td>Brunsbüttel VTS</td>
<td>Go back to process 6. Incomplete process.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Let any incoming vessel enter 1hr/1hr 15m later than the passage time Finkenwerder of the outgoing vessel</td>
<td>Enter means the passing time of E1 buoy for the incoming vessel</td>
<td>Cuxhaven + Brunsbüttel VTS</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ensure meeting of vessels including added beam of more than 90m to take place</td>
<td>Brunsbüttel VTS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

71
Is it possible?  

Brunsbüttel VTS  
If yes, go to 5, if no go to 4.1.3

Table 4: Outgoing traffic process description

Results

The waterway-traffic-environment-system of the River Elbe has been depicted and illustrated with the help of process diagrams based on the process descriptions.
Figure 4-3: Process diagram for the incoming traffic (DIN A3)
Description of the processes can be found in Table 3
Figure 4-4: Process diagram for the outgoing traffic (DIN A3)
Description of the processes can be found in Table 4
4.3 Deduction of the findings towards the research objectives

The process analysis including the discussions on the process maps during the expert workshop allow the following deduction of findings towards the research objectives:

1. ETA gathering, or provision is fragmented. Although ETAs are gathered through 4 channels, 2 of them, written in red, provide the complete list. The ETAs reported by the vessels have to be double checked or confirmed at the last minute by the entities who need it for their operations. PRISE is not in full operation, therefore only the terminals that use it provides ETAs in there.

2. PRISE was intended to be an information system that enables all parties to have the information they need in time and exhaustive. However, it is not in complete operation yet as less than 10 operators out of more than 80 at the port using it.

3. Different methods e.g. fax, telephone is used to gather or provide or check the needed information.

4. It is hard to identify the mandatory procedure in information exchange as well as communication flow in all directions.

5. Information availability and distribution depends on the awareness of the individuals and this is a very error prone process due to the extensive reliance on human operation.

6. Technical and strategic planning requirements differ from each other. Federal VTSs focus on the actual traffic situation. This means, for instance, they need ETA an hour in advance. However, this is not ideal for the strategic planning.

7. Expert workshop revealed that although the legal basis for the traffic management is inflexible, it could be possible to achieve more.

8. Moderation of communication between commercial and operational entities of the system stay unowned.
The process view helps with understanding the working principle of the complex system of the traffic management in a longer tidal waterway. The process view has been simplified in order to make it easier to understand. Nevertheless, it is clearly shown that the interdependencies are high, communication and information exchange is complex and individual-dependent. It can be deducted that daily operations refer to one vessel e.g. to calculate and arrange the passage of an incoming big vessel after the departing vessel passes point of Schulau due to encountering restriction in beam. When the numbers of vessels increase, there is a need for a more efficient and effective system.

Regarding the need for a system-based perspective, its processes and the restriction that are presented under outcomes of expert interviews, it appears that an optimization problem exists.

First, it should be achieved that the information is collected in one place (centralized) and available to all who need it in time and in superior quality (reliable, consistent, comprehensive and valid – Chapter 3.3).

Secondly, the dominating factor in traffic organization should be defined. This thesis identifies it as the number of departing vessels. It determines the berthing places, as an incoming vessel needs a free berth to proceed to the port.

Finally, the levels of optimization should be achieved e.g. maximizing the number of vessels entering and leaving at the same time, best sequence of these vessels to avoid encountering situation, which should serve to system optimization instead of providing individual solutions on a case basis.

The generic model will be presented in the next chapter towards the above-mentioned objectives.
An approach is needed to develop a tool that will help in creating a precise system and in the next step optimizing the complete system.

Conclusion
5 Conceptual outline towards a computational optimization

Overview

The research objective was set to develop a generic model that can serve as the basis for a computer-based traffic prediction and management for the support of decision-making within a system of increasing complexity. Therefore, the question about how to use this generic model i.e. the results of the empirical data collection and the process modelling towards such a computer-based traffic optimization arises. It is the aim of this chapter to provide an answer to this question by introducing the concept (section 5.1), depicting or using the idea of the domain model from ISIMAT (section 5.2) towards an entity-relationship model and by outlining future research (section 5.3). To outline the scheme, the general idea will be depicted at first before the concept becomes more and more detailed.

5.1 Conceptual outline

The computer-based traffic prediction and management for the support of the decision-making refers to the field of computation. Generally, a computation refers to an input of information that is computed, i.e. automatically processed or better calculated, according to a pre-defined set of rules, algorithms or computer programs, leading to the results as exemplary shown in Figure 5-1 (cf. (Schuster, 2001)). Therewith, the question about the contents for the three main parts or categories of the input, so-called conditional statements and the output arises. The desired output will be explained first because one has to know where she wants to go as the part of every strategic process.
The computer-based traffic prediction and management for the support of the decision-making obviously must provide a solution about how to organize the traffic because that is simply the major aim of the tool. This solution about how to manage the traffic must provide a sequence about how to organize the incoming and outgoing flow of the ships because this research was motivated i.e. with the inefficiency of the current “First-come, first-serve”-rule. The inefficiency refers to the second target variable because the provided sequences must be evaluated considering the economic efficiency as well as the navigational risks as the third target variable. These two target variables could be either quantitative by e.g. highlighting a probability factor for an expected navigation risk or qualitative so that the underlying result is simply illustrated e.g. through the lights “green”, “yellow” or “red” of a traffic light. This concept of the three overarching target variables is illustrated in Figure 5-2.
The input variables have been already categorized in Chapter 2 when the waterway-traffic-environment-system was introduced so that the categories and their subcategories should be included (cf. Table 1):

1. Vessel including e.g. the dimensions or input about the equipment, manoeuvrability or itinerary
2. Waterway including the information about the morphology, depth, width, air draft allowance, speed allowance or aids to navigation
3. Traffic
4. Weather
5. Currents and Tide
6. Laws and regulations
7. Logistics
8. Human Factors

As it will be outlined in the next section, future research will have to deal with the question about how to design the input in terms of e.g. quantitative versus qualitative data. Moreover, a prioritisation...
should take place in terms of focusing on the vessel, the waterway, the traffic and the logistics first because these categories were identified as the key elements of the waterway-traffic-environment-system before the model can be extended in a step-wise manner.

Figure 5-3: Concept for the input

<table>
<thead>
<tr>
<th>INPUT</th>
<th>CONDITIONAL STATEMENTS</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vessels</td>
<td></td>
<td>1. Traffic organization</td>
</tr>
<tr>
<td>2. Waterway</td>
<td></td>
<td>2. Efficiency</td>
</tr>
<tr>
<td>3. Traffic</td>
<td>E.g. the composition</td>
<td>3. Navigational risks</td>
</tr>
<tr>
<td>4. Weather</td>
<td>of the type, density,</td>
<td>E.g. a coloured representation for the</td>
</tr>
<tr>
<td>5. Currents and Tide</td>
<td>...</td>
<td>probability of a navigational problem</td>
</tr>
<tr>
<td>6. Laws and regulations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Logistics</td>
<td>E.g. time schedules</td>
<td></td>
</tr>
<tr>
<td>8. Human factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The key element of such a computer-based traffic prediction and management for the support of the decision-making mainly comprises the rules that inherently computes the input for generating the intended output. These rules are also called algorithms that strongly point to the categories of the communication, the information (reliability), the logistics, the coordination of different teams and the complexity management from the framework of Systems Engineering because they have to make sure that the system is designed in an appropriate way. That means that the logical relations between the entities and the rules that have identified are represented in the computational algorithms. Baselines for these logical relations are the process diagrams (Figure 4-3 and Figure 4-4 resp. Table 3 and Table 4), the entity-relationship diagrams (Figure 5-8) as well as the findings.
These findings have already been described in terms of “IF ..., THEN ...”-rules with quantitative information or even thresholds. Nevertheless, the question about how to conceptualize the computational part arises.

Figure 5-4: Concept for the conditional statements

Conclusio

Consequently, a concept has been outlined towards a computational optimization for a computer-based traffic prediction and management for the support of decision-making.
5.2 An entity-relationship model

As explained in the section 1.3, the ISIMAT project led to the results that the view from the own ship to the whole traffic to become encountered during the whole waterway passage is lacking regarding research models in which the underlying relations are appropriately reflected, as ISIMAT considerations were ship-focused, not traffic-focused. Additionally, it was more relevant for the open-sea than for the waterways.

A classical entity-relationship model (ERM) provides a good opportunity to model the waterway-traffic-environment-system. The model uses cells to mirror the relationship between the vessels and other floating and fixed objects so that e.g. various objects can occupy a cell reflecting the morphological characteristics of the waterway. These cells as well as the other entities were specified through attributes in which e.g. the dimension or speed was included. It was examined by (Froese, 2015) that attributes can be given to cells e.g. dimensions and alignment of dredged channel and traffic rules e.g. restrictions; encounters. Attributes can also be given to objectives e.g. vessel type and cargo (e.g. hazardous cargo), dimensions, position and track and speed. Own ship attributes include the three-dimensional vessel domain, speed, acceleration/deceleration and all parameters relevant for safe navigation. Attributes can be static, as e.g. object and cell dimensions are, or dynamic as vessel movement, meteorological and tidal conditions. Thus, the relationships between entities and the attributes will be defined.16

Finally, the ERM provides a flexible workable platform to develop IT-tools for the support of decision-making in vessel traffic management.

To follow this approach, Figure 5-5, Figure 5-6 and Figure 5-7 illustrate the ERM for the Hamburg Port Authority including the Port VTS and for the Other VTS Centres as both are the traffic organizers.

---

16 ... as in case of strong wind e.g. the attributes “direction of wind and force”, “ship heading” and “stability” must provide the input data to calculate the increase of the ship’s draft by wind-caused heeling."
along the River Elbe. Both entities monitor the conditions - weather, currents and tide and the waterway -. Despite of the fact that they monitor different areas of the waterway, both follow the same task. It was one major outcome of the field interviews and the process diagrams that would lead to inefficiencies. To see this clearly both diagrams are integrated in Figure 5-8, comprising the other actors within the system.
Figure 5-5: Illustration of the domain Entity-relationship model for HPA (DIN A3)
Figure 5-6: Illustration of the Entity-relationship model for the other VTS Centres (DIN A3)
Figure 5-7: Illustration of the integrated Entity-relationship model (DIN A3)
Figure 5-8: Illustration of the proposed solution (DIN A3)
The proposed solution as it is shown in Figure 5-8 is towards a centralized system governed by the Port Authority who runs the port VTS. The reasons for this:

- Port authority is the only entity who has the complete overview of the traffic which consists of the information about the vessels and how they are terminal-wise planned.
- Interviews revealed that the final and the correct information is gathered from the port authority.
- Its core competence fits for the role given, which is to cover the whole port and the process, and ensure that all these runs smoothly.
- It is mentioned during the interviews that the system should work stricter (goal-oriented system) considering all the mentioned trends in shipping and restrictions along the waterway. From the SE perspective, it is ideal in a goal oriented designed system to have a clear owner or leader who has the capacity and capability to ensure smooth running of processes.
- Additionally, the port authority has all the technical and functional preconditions.

It can simply be exemplified how it should work as it follows: The number of outgoing vessels should be the determining factor in traffic organization as they must leave the port to allow the incoming vessels to have berthing places. This logic relates to the big vessels only. Terminal-wise planning of the vessels should be communicated to the Port VTS. Port VTS should check the navigational side of the planning whether it is in line with the traffic requirements. Then, the Port VTS communicates it to the VTS Centre at the entrance of the waterway, in this case the Cuxhaven VTS. There the planning of the incoming vessels will be matched to the existing availability. Weather, tide, current and the restrictions of the waterway will be taken into account. With the help of a computer-based traffic prediction and management programme different application scenarios can be tested about how it is optimal to organize the traffic.
in order to exploit the capacities. This might mean waiting times for some vessels. However, the goal is to increase the total throughput on the system-level, not the easiness of one vessel on the level of the elements. Therefore, the developed model should support the decision-making in a system of increasing complexity.

The proposed process ensures a clear picture of the communication partner(s) for each entity which was mentioned as being one of the main bottlenecks during the interviews. This should mainly ease the complexity and remove the confusion of the high number of decision-making authorities. Complementary to this easiness, an information collecting and sharing system, one can name it PRISE or else, is also one of the main components of the solution method. As the interviews revealed, the fact that 100% participation with reliable, consistent, comprehensive and valid information to the platform is the key to success, and it is necessary to moderate commercial and operational interests of traffic organisation. This is a suitable task for the administrative authority, in this case WSV, which is the governing body of laws and regulations for the waterway. A clear distribution of responsibilities around a centralized system makes the cooperation easier for all the other actors involved, and that will move the system towards the optimization goal.

Performance metrics

How to control and improve the proposed new processes? In literature, the performance of the logistics systems is mainly measured through four elements (Schulte, 2009);

- Time,
- Costs,
- Quality and
- Flexibility.

Time could mean here i.a. both the reaction time of the system and the delay times for the vessels. How quick the system reacts to the enquiries could be one measure to control the efficiency of the system. Delay times, not for an individual vessel, but for the system in the long run, which includes the early information sharing to avoid
unnecessary waiting times, is another component of the efficiency measurement.

Identification of the savings in comparison to the former process flow can bring up the **cost** item as a metric to control the proposed process. This is also connected to the outcome that the system should work goal-oriented in the future. It means that by early information sharing some vessels can reduce their speed to avoid waiting times at the entrance of the river and thus, to save fuel cost through slow-steaming.

**Quality** could refer to the satisfaction of the shipping companies. How often a wrong decision is made, which causes an incident or accident in comparison to former processes, is also another factor to control and improve the quality of the processes.

Lastly, the reaction ability and solution provision to the last-minute happenings are the **flexibility** measure of the processes which plays an important role in the continuous improvement of the operations.

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A conceptual entity-relationship model has been identified that suggests a more elaborated and centralized organisation led by the port authority that will lead the traffic organisation. Moreover, the administrative authority that governs the legal side should moderate the commercial and operational interests. Thus, both organizations can concentrate on their core competence, which should motivate the other actors to actively take part in the optimization of the system.
5.3 Quality Function Deployment (QFD) method for future research

To derive an understanding about how to proceed for reaching the research objective the concept towards a computational optimization tool in the previous section has already outlined the next steps because all the attributes that were introduced must be specified regarding their qualitative or quantitative forming. Therefore, a systematic approach is needed, which can take the processes explicitly into account, has a focus on optimization and tries to consider the needs of all stakeholders involved. The Quality Function Deployment method is a tool to find the optimum technical solution for given customer requirements so that it represents a systematic way to identify the optimum technical solution, here the optimum process. The QFD method is based on the idea that the characteristics and the quality of a product, here the process flow, should be basically the result of the customer requirements and not what is technically possible. Because of this, it is the task of the QFD method to figure out the customer requirements and check whether and how they can be realized. To do so, a matrix is created in which the customer requirements on one side and the product characteristics on the other side are mapped so that the biggest overlapping areas can be identified. Since its creation and depiction by Bob King in 1984, this method has been developed further and different schools or focus areas that can be distinguished. For example, (King, 1989) mentioned 18 different steps that were extended according to (Kerth, et al., 2009) through seven further steps to create a more dedicated decision, while (Vorbach, 2007)


just mentions four different phases – quality planning of the product, planning of the parts, planning of the processes and planning of the production. Nevertheless, all these different varieties or focus areas of the QFD method highlight the concentration on quality standards and take all relevant stakeholders explicitly into account. An exemplary illustration about how the waterway-traffic-environment-system for the Vessel Traffic Management could be covered can be seen in Figure 5-9. The QFD method can therefore be prominent for any follow-up research as a guiding methodology.

Figure 5-9: QFD framework for future research with reference to (Vorbach, 2007, p. 335)
As a result, it has been argued that future research should focus on a re-design of the organisational solution for the Vessel Traffic Management as conceptually outlined above. For doing so it is proposed to investigate the potential of the QFD method because of its focus on quality standards and the needs of all relevant stakeholders explicitly into account. Thus, the outlined conceptual model could be fine-tuned before a simulation-based prediction and management tool can be developed.
6 Concluding remarks

Based on the introduction of continuously increasing world trade allowing for goods and capital to exchange freely that requires effective and efficient transport systems in which the majority is transported by vessels the fierce competition between shipping lines was introduced. This fierce competition was explained through their effort to gain competitive advantages e.g. with the help of economies of scale. In contrast, it was explained that waterway dimensions cannot increase with the same speed as the tendency to build bigger container vessels does. In this context by using the example of the River Elbe, it was highlighted that “margins of safety of navigation are being increasingly exhausted because ports want to keep pace with ship development to not lose business” (Froese, 2015). Against this background the research question was derived about

how to approach the navigational risks and the efficiency of the traffic management in longer tidal waterways?

The lack of research regarding explanation approaches or models focusing on the sequence of vessels in waterways with the objective to optimize the whole traffic flow motivated the objective to develop a research model with whom it becomes possible to better optimize the complexities and risks of the vessel traffic management in in longer tidal waterways by making use of the maximum available capacity without impairing safety (Chapter 1).

The Vessel Traffic Management in longer tidal waterways was then introduced and characterized as highly complex because essential influential factors affecting the navigation showed how demanding it can be to get to the ports, which are not adjacent to the open sea. For diving deep into the status of the current traffic organization, the dynamics and complexities of the waterways were explained in more details. Traffic management should be adapted to these conditions in order to support efficiency and safety of navigation so that a holistic perspective is needed. In this regard, the River Elbe was depicted as the most complicated river in Europe, so it can be
assumed that if a solution can support the situation there it can support it everywhere. The system elements and the boundary are almost the same for a traffic management system with one or two different entities/actors/conditions. With the help of the introduced framework from Systems Theory and Systems Engineering, one main task was set to position the problem-solving capacity of the current organization of the Vessel Traffic Management regarding the external requirements in terms of the complexities of the system. Each region should be able to identify its own complexities and use the example of the River Elbe approach, provided by this dissertation, in order to transfer the results. Because of the identified gaps of knowledge, the research objective was then to develop a generic model that can serve as the basis for a computer-based traffic prediction and management for the support of decision-making within a system of increasing complexity (Chapter 2).

Because of this lack of research, expert interviews were selected as the research methodology for the empirical data collection comprising hypothesis generating and confirming aspects. By answering essential questions about the concept, the type, the execution and the participants (including the reasons), the design of the expert interviews was outlined towards the goal to understand the system, its complexities and the underlying problems from a system-based perspective. The results of the expert interviews pointed towards the conclusion that an overarching comprehensive perspective is needed that is consistent and reliable because of the decentralized decision-making processes against the background of a high informational, dynamic and structural complexity. In order to reach the ports that are not adjacent to an open sea, more reliable, and accurate information has to be provided in time as well a safe and efficient passage has to be ensured (Chapter 3).

With the help of the framework of the Business Process Modelling, the whole waterway-traffic-environment-system of the River Elbe was covered through the depiction and illustration of the process diagrams (Chapter 4).

These diagrams revealed and confirmed the high interdependencies, complexity of communication and information
exchange. Thus, the traffic organization currently refers to one vessel and the solutions provided are individual-dependent which means assessing the situation, in this case sequencing the vessels, depends on the individuals – VTS operators. With the dramatic increase of the number of large vessels it is hard to pre-plan and manage complex traffic situations. Therefore, it is hard to identify the capacities available and the way to exploit them. This reveals the need for an approach to develop a tool that will help with creating a precise system is identified. As the aim is to use the existing infrastructure more intelligently, a precise system leads to an improved traffic in longer tidal waterways in terms of efficiency (maximum throughput, minimum waiting times and delays) and risk mitigation (detectability of the encountering situations in advance). This should additionally allow optimization in the further steps. A generic model will be developed to serve the identified need (Chapter 5)

Chapter 5 outlined a concept towards a computational optimization for a computer-based traffic prediction and management for the support of decision-making. In this regard, a conceptual entity-relationship diagrams were derived that suggested a more elaborated and centralized organisation led by the port authority that will lead the traffic organisation. Moreover, the administrative authority that governs the legal side should moderate the commercial and operational interests. Thus, both organizations can concentrate on their core competence, which should motivate the other actors to actively take part in the optimization of the system. Finally, it was argued that future research should focus on a re-design of the organisational solution at first because one major result was that the port should organize the traffic. This will secondly lead to fine-tuning of the diagrams and their corresponding functions before the data model and the question about how to exactly compute, i.e. to write the software program, are dealt with in a third and fourth step.
The innovation aspects of this PhD thesis are fourfold:

1. The well-known inefficiencies and navigational risks of the Vessel Traffic Management in longer tidal waterways were analysed from a Systems Engineering based perspective. Therefore, the problem was analysed with the help of a theoretical framework that is often lacking in the context of maritime logistics.

2. The lack of empirical information could be closed with the help of the expert interviews and workshops. This should also be understood as an innovation because it helped to scientifically derive and confirm hypotheses of the cause-and-effect-relations.

3. It was outlined that a holistic view covering the causal relations of the entire system was missing. The process diagrams of the incoming and outgoing traffic flow present a new and therefore innovative solution. Moreover, the diagrams make it easier to identify the inefficiencies within the traffic organization as well as the risks that are brought with it.

4. Finally, the conceptual outline of a computational model based on the created entity-relationship diagrams is an extension of current knowledge because it provides the guidance and a flexible platform about how to build a simulation-based tool in future research and enables to derive conclusions about how to organize the vessel traffic safely and more efficiently.
7 Appendix

Expert interview 1 – Ben Lodemann, Hamburg, 20 February 2015

Participants
Ben Lodemann – Elbe pilot
Jens Froese – Professor of Maritime Logistics
Ilknur Colmorn – Research Associate

Purpose
Pilots face the complexity and challenges of navigating along the waterways directly onboard the vessels. The experience the interaction between the vessel and the waterway at the first place. They are one of the components of the system. Therefore, it is seen crucial to discuss the topic of vessel traffic management in the River Elbe with the Elbe pilots.

Results
- Communication difficulties and complexities, e.g. due to the responsibility areas, are mentioned which make the traffic organization more difficult.
- High number of decision-making authorities are mentioned as making the system more complex and narrowing down the possibilities to exploit the capacities of the waterway.
- The procedure how the ETA is gathered from the pilots is explained and attention is taken to the difficulty of getting a reliable, consistent and up-to-date ETA with examples.
- The planning behind the scenes, getting a vessel in or out of the port, is explained in detail which shows the importance of getting the necessary information on time and in a less complex way than as it is practiced at the moment.
- Communication possibilities and cooperation partners are mentioned as being the 2 principles to coordinate the bigger vessels.
o Awareness of the necessity to share information, instead of sharing upon request, is mentioned to be lacking. Therefore, it is recently told the agents that if they do not provide ETA on time, the delay will be inevitable.

o The importance of considering Elbe as a system and need for one coordinator is explained that by this way the pilots would be advising a system which gives them a full picture of the traffic instead of advising one individual vessel.

o In order to achieve a system based perspective the attention is taken to the proper description of the system with necessary inputs and the desired output.

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**Expert interview 2 – Jörg Pollmann, Hamburg, 12 March 2015**

**Participants**

Jörg Pollmann – Harbor Master

Jens Froese – Professor of Maritime Logistics

Ilknur Colmorn – Research Associate

**Purpose**

Port authority should have the whole overview of the waterway and play an important function in planning.

**Results**

o The idea behind PRISE is explained. It was to exchange information. The planning procedure is explained which is usually made days in advance, however, the last-minute changes can make it hard to follow.

o Not all the terminals are connected to the PRISE system. The ones that are not involved are collected by the Feeder Logistik Zentrale (FLZ) and entered to the system which only concerns the terminal operators, not the VTS.
- Appendix -

- It is from the beginning on wanted that such an information sharing system should automatically be updated and be connected to the planning tools of the participants. It is added that this might make it technically complicated in the development phase, however, it will be a reliable and workable system.

- It is explained how the traffic is coordinated between the Port VTS and the terminal operators. Planning tables were shown which show conflicting areas in red as well as way-time diagram.

- It is mentioned that when it comes to waiting times whoever needs to wait starts to complain although the conflicts are sometimes knowns days before.

- The importance of providing accurate information on time especially by the terminal operators regarding the completion of operations is mentioned.

- The awareness the optimize the whole port activities, not its own terminal, is said to get better in the recent years.

- The idea and motivation behind the establishment of FLZ and NTK is explained so that the terminal operators should among themselves coordinate the planning, FLZ for feeder vessels and NTK for bigger vessels.

- It is added that the duties of FLZ and NTK should not be the duties of VTS, however, the result is important for the VTS.

- It is agreed with the harbour and river pilots passing of vessels at the port area is done with the help of tug boats.

- The planning of the meeting positions is made by gathering the AIS signals from the vessel and based on the average speed. When it is seen that the vessels need to modify the speed the information is passed to Cuxhaven VTS.

- There have been voluntary agreements between some shipping lines to get into direct contact to inform about the conflicts in advance even if they are not yet within the German waterways which is required from the law point of view. This approach is advantageous in the long run.
- Appendix -

- Not sufficiently increasing water level is mentioned as being of the restriction due to easterly wind.
- It is mentioned that everybody is interested in only their part of responsibility. This shows the lack of system approach.
- Future plans such as kind of slot regulation are mentioned as being under discussion.
- The number of extraordinarily big vessels (330m L / 45 B) has increased 60% in the last 6 years. Port of Hamburg was called by 972 of these vessels in 2014. It is known from the shipping lines that within the next 2 years number of such vessels will increase another 40%. So, the system should work stricter to cope with the restrictions.
- Technical possibilities, such as “port monitor” and “interactive table” were briefly explained.
- Fairway adoption plan is mentioned which confirmed the long duration of infrastructural changes. Therefore, it can be deducted that the only way to grow economically is to use the waterway more intelligently.
**Expert interview 3 – Cuxhaven Pilots, Cuxhaven-Hamburg, 20 May 2015***

*These interviews took place on a vessel called “station vessel” for the pilot in Cuxhaven. In addition to the personal interviews with several pilots it includes an observation of the activities of whole day.

**Participants**

Several pilots on board

Ilknur Colmorn – Research Associate

**Purpose**

Cuxhaven is the entrance to the River Elbe which means the first ETA point triggering all the processes ahead.

**Results**

- Communication is mentioned as being complex as there are many parties involved in it and every actor sees his part differently.
- It is mentioned that not all the vessels are connected to the PRISE, therefore, the information necessary for the them is gathered from the agent per email or fax.
- No matter what information is received and there, many pilots call the port authority before entering the river to check if the plan still stays the same which means mainly that if the vessel has a berthing place.
- First come first serve rule applies to all is confirmed.
- It is added that sometimes for the special vessels, i.e. big, deep draft, tide dependent, when the berth is free, and the circumstances are fine, they directly call the agent to ask if the vessel can arrive earlier.
- It is mentioned that a list of vessels, except the small ones, with their ETAs and berthing places is received on board the pilot station vessel. Other vessels send their information via email or fax. Given ETA might be to the pilot station or to harbour and needs to be checked.
o It is added that the last-minute changes occur very often. It can happen to get a call onboard the vessel that the vessel should not enter, or the agent might decide still to enter and anchor at Brunsbüttel until the time to proceed the port.

o Some facts are listed: From Cuxhaven to Hamburg harbor is 70 miles, from Brunsbüttel to Hamburg harbor 36 miles. From Cuxhaven to Brunsbüttel takes in average 3 hrs., depending on ship’s speed and current. Big ships can make 20kts. At high tide with the current it takes around 6hrs to Hamburg and against the current about 7hrs.

o Outgoing vessels (tide-dependent) leave Hamburg at the low tide. Weather restriction is for big ships above BF 7 and for the others above BF 8.

o Even if it is not an official restricted area, the pilots try avoiding encounters at the corner after passing Cuxhaven.

o It is known before where the 2 vessels should meet. This information comes from either VTS Cuxhaven or Brunsbüttel. They are in contact with VTS Hamburg and they inform the pilots whether they are too fast or too slow.

o All the planning is mentioned to be made either in Cuxhaven or Hamburg and it is known which one will meet which at what time.

o It is mentioned that there is no regulation on how much distance to be left between 2 vessels. Pilots do it according to their safety understanding and feeling (1-1.5-2miles maybe).

o Like the distance, it is mentioned that there is no regulation to keep any specific speed, it is mostly adjusted according to allowed arrival time in Hamburg.

o An example of that morning was given that there was 4 incoming and 2 outgoing big ships. One of the outgoing ship met the 3 of incoming ones between Brunsbüttel and Cuxhaven and the last one after passing Cuxhaven.

o If the berthing places are available 4 big ships can enter one after another at the high tide.
Expert interview 4 – NTK, Hamburg, 5 June 2015

Participants
Gerald Hirt – Head of NTK
3 Colleagues in the operations department
Ilknur Colmorn – Research Associate

Purpose
How the vessels are terminal-wise planned is one of the main pillars of the planning and organization of the traffic management. NTK is known to start new to take the role of better planning of the commercial side of the port. NTK is financed by HHLA and Eurogate.

Results
- It is acknowledged that the traffic planning for a river like Elbe plays and important role as the widening and deepening of the river do not relieve much burden considering the big vessel in operation now.
- The distinction of the commercial and nautical decisions was explained. It was the triggering point for the container terminals to take initiative to establish first FLZ and now the NTK.
- The aim of the NTK is to act as a communication coordinator among all terminals (not only container), carriers/agents, authorities (HPA-VTS), service providers (tugs) and previous ports. The objective is to collect all the information from all these commercial partners and to communicate the operational requirements to HPA.
- The main driver behind NTK is that the shipping lines say that the terminals at the Port of Hamburg are reliable, safe and efficient. Reliability refers to having early and correct information including traffic flow.
- It is added that the planning and calculations are done manually now. But there will be an IT system soon which will
also provide a transparent reporting. Maximum participation is desired as it costs something.

- This new IT system will be complementary to PRISE. It is said to take away a lot of manual work and will be able to produce an analysis. Therefore, the information from PRISE can be analysed by NTK with the help of the IT system.

- ETA, ETD and draft are mentioned as being the most important information.

- An example was given to picture the restriction levels: When leaving the CTA terminal, the bridge must be passed on the low water while the shallow water area, Schulau, which comes after bridge should be passed on the high water. Current must also be taken into account. Thus, in a very small area there are many restrictions. Incoming ships enter with the tide, therefore main challenge is with the outgoing vessels.

- Main restrictions are listed below:
  - Turning restriction at the port
  - Tide restrictions for each terminal
  - Bridge
  - Current
  - Shallow water area, Schulau, just after departing the port
  - When a big vessel passes by CTB or Eurogate they need to top up their gantry cranes.

- NTK has now 5 workers working from 06:00 to 23:00. Later it will be 24hrs operation with 3 shifts. Most important skills are moderation, communication and soft skills.

- It is added that there will never be in River Elbe 25 meters water below and very wide channel like in Rotterdam. Therefore, there is a need to work strictly on traffic planning. However, most importantly the reliability and cost efficiency counts.
Expert interview 5 – Jörg Pollmann, Hamburg VTS Centre, 24 June 2015

Participants
Jörg Pollmann – Harbor Master
Prof. Jens Froese – Prof of Maritime Logistics
Ilknur Colmorn – Research Associate

Purpose
This interview took place in the VTS Hamburg in order to see the VTS centre on site and understand how the planning is handled here.

Results
- It is seen on the site that the port VTS has advanced technology to support the vessels and the traffic management.
- Way-time diagram and other planning tools are shown by the harbor master explained how they are used in the planning.
- As there has been unclarity in gathering ETA of all vessel coming to Hamburg, he explained that the information of incoming ships is gathered from their AIS data automatically to the system (DV-Elbe 1 is the IT system of the port). From the average speed (constantly updated) it is calculated where it will be. Only the time that the vessel is berthed is entered manually as the signal is not reliable when the vessel is in the harbor area.
- He added that the berth information is completed by the VTS personnel (via agent or NTK nowadays). This list is shared with the pilots.
- When it comes to make the planning, and sequencing the vessel and fixing this plan, he added that it is partly done that way. However, sometimes according to different point of views, there comes suggestions to change the plan which is not always possible. All entities come together regularly to communicate and discuss the improvement potentials.
Expert interview 6 – Harbour Pilots, Hamburg, 29 June 2015*

*These interviews took place in the harbour pilots’ station in Hamburg within a period of 5 days (Monday to Friday). In addition to the personal interviews with several pilots it includes the observation of the activities of the days as well as getting onboard of vessel with the pilots.

Participants

Several pilots at the station

Ilknur Colmorn – Research Associate

Purpose

Cuxhaven is the entrance to the River Elbe which means the first ETA point triggering all the processes ahead.

Results

- Pre-planning is made by HPA. Incoming ships appear on the computer screen automatically. Outgoing ships are planned according to their order from the agent. Only in special cases, if something is not clear, it is communicated with the VTS.
- Outgoing vessels information is passed automatically on the computer screen to the VTS. They see this way the plan of outgoing vessels.
- Agents order the pilot 2 hr before departure, for the big ships 4 hrs before departure and they already discuss with VTS and know what time is the latest time to order the pilot.
- The ETA information of incoming ships is received from VTS and Schiffsmeldedienst. ETA is the point to the border of Hamburg.
- There is 2 hrs time window after low water for the vessels to depart.
- Vessels leave the port at low tide to meet the high tide between Glückstadt and Brunsbüttel.
- Bridge area (Köhlbrandbrücke) has its own tidal window for the big ships. Due to the draft, vessels need the high-water level but also need to take care of the bridge height. They
additionally need to pass the area between Glückstadt and Brunsbüttel (Schulau) at the high tide. All additional costs are paid by the terminals, e.g. 4 tugs instead of 2.

- For this reason, it happens sometimes that the vessels depart at the high tide and moored at Finkenwerder and wait for the low tide to depart again to meet the high tide between Glückstadt and Brunsbüttel.
- Tug and boatmen limits are more than number of pilot’s limits.
- When information for a vessel, e.g. berth etc. is needed the responsible pilot asks the watchmen and he figures it out with HPA or VTS.
- Pilots get a notice of 90 min to be in the pilot station. He leaves for the vessel 1 hr before the departure time – it is called taxi time to the terminal-. There are changes occur in the time of departure. For example, for a ship which will depart at 06:00 he is ordered pilot before 04:00. If the agent didn’t check the situation in the night or checked later than 04:00 it is too late for the pilot who is on the way to the ship. Now to avoid this situation pilots say that after 1 hr waiting time onboard they have the right to leave the ship. Ship must order the pilot again.
- FLZ improved the planning however there are still agents who do not update during the night. Normally in the terminal at 07:00 the shift ends. Pilot is ordered for 06:00 but due to some reason ship is delayed but this information is not passed through. This happens quite often.
- Pilots prefer an approach of solution-based and silent VTS.
- October-March is the dredging season. Mud is taken off and put aside and of course it comes back later.
- There are 74 pilots and for the moment 30 pilots to be called in a day.
- Sometimes it is communicated with the Cuxhaven pilots when they want to double check the order of ships.
Expert interview 7 – Rolf Ehlers-Maaßen, Brunsbüttel, 5 August 2015

Participants
Rolf Ehlers-Maaßen – Head of VTS Brunsbüttel
Prof. Jens Froese – Prof. of Maritime Logistics
Ilknur Colmorn – Research Associate

Purpose
Brunsbüttel VTS is responsible for the passage where the encountering restrictions exist.

Results
- It is confirmed that the planning is made by the Port of Hamburg and noted that the task of VTS Brunsbüttel is to prevent vessels to have a forbidden passage in the area.
- VTS Brunsbüttel is also responsible for making the planning for the outgoing tide-dependent vessels. For the incoming tide-dependent vessels the responsible party is the Cuxhaven VTS.
- Brunsbüttel VTS provides the earliest and latest time of departure from the port for the outgoing tide-dependent vessels. This information is shared with the Cuxhaven VTS to check if there is any conflict with and incoming vessel.
- VTS Hamburg is given the earliest and latest passing time of jetty Schulau for the outgoing tide dependent vessels. They put it in the written form and send it by fax.
- Examples of passage planning both for a tide-dependent and non-dependent vessel are given which help to draw the process diagrams.
- Regarding the gathering of information, the means are listed as below:
  - PRISE
  - 40m list from PRISE (It is an ETA list of vessels which have 40m and above beam)
- Appendix -

- 40m fax from the port distributed to VTS Brunsbüttel, VTS Cuxhaven, Elbe and Cuxhaven pilots. This differs from the above-mentioned list of PRISE.
- A lot of telephone communication
  - It is noted that there are regular meetings recently started with all entities to seek for the improvement potentials in the communication.
  - Some accident examples were given (black-out of vessels, 336 and 366m long) and said that it did not luckily not cause the closure of the River Elbe.
  - Another accident of a 336m long vessel in the area where the fairway is 370m wide cause a close of the traffic along the river.
  - In the cases of accidents radar pilots at VTS Brunsbüttel provide assistance.
  - It was mentioned that the scientific investigation of increasing the added beam encountering limit in some areas to 92m is underway.
  - It is noted that there is an internal document showing speed limits in different areas.
  - It is noted that for the wide beam vessels, even a small list means a considerable change in draft. All the parameters squat etc. are entered in the calculations where WSA Hamburg is making. This is the basis of the tide tables (shown on the paper form) and based on these tables is the computer program where it is calculated to see at what times the vessel should pass certain points. This program is used by VTS Brunsbüttel and Cuxhaven. Hamburg has the paper for of tide tables.
  - When it comes to water level prognoses and the decision of letting the vessel leave the port or stay in case of not sufficiently increasing water Cuxhaven and Brunsbüttel make decision. It can happen that a 15,10m draft bulk carrier stays several weeks outside due the negative water level prognoses and only for 10cm difference.
  - When it comes to seeing the whole picture of incoming and outgoing vessels in the short term, it is mentioned that they
have their own system which is called DUAL traffic. They can see the area of Brunsbüttel, Cuxhaven and 20km off the North Sea. ETA is mentioned as an information which is not necessary for Brunsbüttel although it is in PRISE.

- The degrees of responsibility when the vessel arrive to the River is mentioned as being an issue of clarification when it comes to the role of NTK.
- It is mentioned that every case is different and there is no general recipe. With no restrictions applying to a vessel and a given ATA it works perfectly. However, last minutes changes occur quite often.
- It is confirmed that each party considers their area of responsibility and when something changes due to some problems on another side, they complain about it.
Expert interview 8 – WSA Hamburg, Frank Richters, Hamburg, 18 August 2015

Participants
Frank Richters – WSA Hamburg
Prof. Jens Froese – Prof. of Maritime Logistics
Ilknur Colmorn – Research Associate

Purpose
Brunsbüttel VTS has directed us to WSA Hamburg where there is more to discover about the planning, especially for the tide-dependent vessels.

Results
- It is confirmed that the meeting situations are controlled by VTS Brunsbüttel. However, they also need the information about the coming ships which they only know that they are coming but do not know what the plan is and how they are terminal wise it is planned. For the outgoing ships, they don't know how much loading/discharging left, which tide window the vessel will use etc. When all these are planned, Brunsbüttel will be informed about the departure. Then they can check whether the plan made there fit to the area and rules.

- It is mentioned that they try to keep everything transparent so that everybody can make the planning by and for themselves.

- It is said that one responsible for the whole river would not be practical and correct as sections of the river are different. With a proper information flow, it should work in order. There is Elbe nautical group for this reason to exchange ideas and improve the information flow. It should be made sure that it works between the VTS centres.

- Easiness of the operation besides the safety with regards to the VTS regulation in Germany is discussed shortly. Easiness is explained that the traffic can flow without restrictions and free.
Less communication takes place and every vessel finds its own way under the right conditions.

- Economic side of the port is acknowledged and said that it is another area of responsibility.

- Silent VTS which intervenes only when there are deviations than normal traffic is briefly discussed. However, it is added that as the traffic density has increased, and the river has its restrictions there is more communication, at least to make the others on the traffic are aware of each other’s deviations. The river is never a free space for one without any effect from another.

- It is added that radar advice is on place when there is emergency anchoring, disabled vessels among others. Although the technology on onboard as well as the PPU devices are advance, radar advice is said to be necessary especially when there is an incident. They take over in the process of solving the problem and coordinate the flow sequence so that the traffic can easily and safely flow. It is explained as the distinction of receiving the information ready from outside and collecting it by herself. In the former one can concentrate himself on the emergency than the traffic around.

- Recently occurred NYK Olympus accident was explained how she was kept stable with tug boats against a strong current.

- The fundamentals of tide software are given as a paper. Calculations are made according to the reference vessel. An incoming vessel with a maximum draft of 15.10m has 20 minutes tide window where she needs to pass Vogelsand Turm, not earlier and not later.

- The distance depends on the speed. When a vessel leaves Hamburg, the average speed is 6-8 kt. The distance can become a bit less, but in the river with the increasing speed it should increase. For 2 months it is written in the internal regulation that 3nm distance to be left between 2 big vessels. It is calculated accordingly that with the speed of 12 kts when she needs to stop, she can do so in 2nm but not anymore under control which end up with grounding. With 3nm she can stop in
a controlled way and still be able to manoeuvre and stay in the dredged channel.

- Above mentioned principles are clear to the VTS operators. However, it is acknowledged that they do not have any support system to calculate maximum input without getting into encountering situations. It is done according to knowledge and existing rules, such as tide window, distance and speed among others.
- It is noted that the planning works flexible at the moment and the capacity limits of each area are not known explicitly. The work is in progress in this respect.
- The encountering area with an added beam of not more than 90m is confirmed. It is also acknowledged that unofficially 92m is tested and seen how the vessels react to encountering in the area.
- It is added that although there are plans to create meeting areas with more allowance it is acknowledged that there will always be meeting restriction in the river.
- It can be derived from the recent ship calls that the vessels with a beam restriction have called Hamburg more than the vessels with tide restriction.
- It is confirmed that the administration has the rule of first-come first-serve, no queuing of the vessels and it is mainly because of the commercial planning of the vessels. It is not known by the administration how the vessels are terminal-wise planned. Planning is done therefore according to navigational requirement only.
- It is acknowledged that the commercial side of the planning plays also a decisive role. The Port of Hamburg is seen as the coordinator of such interests.
- It is mentioned that they do not rely on the information in PRISE.
- NTK role as an early planner is acknowledged. Pilots and VTS do the fine tuning of the planning on site.

*This interview carried out through email communication with the questions which would better explain the ETA/ETD procedure of the processes.

Participants

Julian H. Rauch – MSC Hamburg
Ilknur Colmorn – Research Associate

Purpose

Agents play an important role in providing important information about the vessels’ arrival and departure.

Results

o Julian H. Rauch has answered the questions about the reporting of ETA/ETD procedure. He mentioned that agents report their berthing plan to all the authorities including other external stakeholders (boatmen, tug company etc.) with a copy to elbe pilots. The berthing plan has already and ETD. 4 hours before the completion of operations terminal inform the agents and they inform all the other parties.

o Means of reporting depend on the time left. It is by email or by phone.

o Vessels report their ETA 36h/24h/2h/6h in advance to eta.elbe@elbe-pilot.de.

o They do not have access to PRISE.

o When it comes to cut&run scenarios they are discussed between the port agent and the company fleet -network-terminal-efficiency department in headquarters and communicated with the terminal.

o When it comes to getting the green light for a departure, the agent already checks the meeting restrictions and tide situation in advance when he is doing the planning. He stays in contact with the authorities and any changes are communicated with everyone involved.

Participants
Jörg Pollmann – Harbor Master
Hartmut H. Hilmer – WSV Kiel
A representative from the WSA Hamburg
Rolf Ehlers-Maaßen – Head of VTS Brunsbüttel
Tim Grandorff – Chairmann Hamburg Port Pilots
Anton Kunze – DAKOSY Port Communication Services
Prof. Jens Froese – Prof. of Maritime Logistics
Dr. Svenja Töter – Erasmus University Rotterdam
Ilknur Colmorn – Research Associate

Purpose
To receive feedback from the interview participants about the outcomes of the interviews. Moreover, it should help to clarify, extend and increase the quality of the information collected through the interviews. Finally, the process diagrams are to be discussed with the group to get their validation.

Results
- The outcomes of the interviews are briefly presented. This included the process diagrams. Open questions considering the process are set as a starting point for the discussions. The difference between the information gathered from the documents (30m and 40m lists) and different IT systems are reclarified.

- A point was made to the difference between the technical and strategic planning. Federal VTSs concentrate on the actual traffic situation in the river and for them it should be enough to receive the ETA 1 hr before. However, this is not sufficient for the strategic planning.
- It is mentioned that a close confidential contact between all players is important. Information exchange in all directions is necessary. When the parties need to double-check the information in the PRISE it is not confidential anymore.

- Slot system of the airline industry is mentioned and said that it is the future for the ports to work like it. It is under progress from the legal point of view. Number of outgoing vessels should be the governing parameter in this case. It should work as a compulsory system and anyone who is not participating should be the last in the slot.

- It is added that there are more than 80 terminal operators within the Port of Hamburg and less than 10 operators are connected to the PRISE system. The system is still under development. Its aim for the future that all the terminal operators will be connected there, and it will technically be also developed further.

- Some unofficial flow in the process diagrams (e.g. 92m allowance of the added beam instead of 90m) has been discussed and concluded that the system allows more flexibility than the written rules. However, many of these allowances are kind of proposals for the vessels/vessel command.

- Problems related to the availability of sufficient number of tug boats are discussed. This is especially relevant for the big vessels. Some examples were given that it had happened that one vessel had to wait at the North Sea because of the lack of tug boats and due to other big vessels calling the port at the same time.

- The scenarios that can happen when the water level not sufficiently increases are discussed. An early forecast is available; however, it is still a prediction. When it happens for example 2 hours before the planned departure, there is not much to do. Shipping lines and terminals do not like to deal with cut and go situation, because it is on one side very expensive to load and then again to discharge the containers, and on the other side it is not discharging 30 containers. One has to discharge the complete load to organize the Bill of
Ladings for instance. Moreover, as the beam of the vessels become wider, they can get more cargo at the bottom of the vessel and use very little ballast water. Therefore, there is not much to do with ballast.

- Regarding the distance to be left between vessels in a convoy, it is said that the departure tide window is 2 hours with the maximum draft according to the legal point of view in the latest fairway adaption plan. This means 4 ships can come in within this time, one in the beginning, one at the end and 2 in between. That means that they will have 40min distance between each other. It depends on weather conditions and traffic that it can be sometimes 5 vessels out or 5 vessels in. These are according to the reference vessel (Bemessungsschiff) in the fairway adoption plan.

- The list of facts and restrictions about the River Elbe is discussed item by item and updated.

- Process diagrams of incoming and outgoing traffic were distributed to everyone and discussed point by point to clarify the open questions as well as validate them.
### Tables for process description with more information

#### Standard Process Description – Incoming traffic

<table>
<thead>
<tr>
<th>Process Description</th>
<th>Function</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process</strong></td>
<td><strong>Hamburg VTS</strong></td>
<td><strong>Brunsbüttel VTS</strong></td>
</tr>
<tr>
<td><strong>Gather ETA</strong></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1.1 ETA is entered into PRISE</td>
<td></td>
<td>Only some terminal operators are connected to PRISE</td>
</tr>
<tr>
<td>1.2 ETA of all vessels collected by the IT system of the port</td>
<td>This is the first official channel to gather the ETA. Port has its own IT system, which gathers ETA through radar and AIS signals, that is also accessed by all VTS centres. This is</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>one of the official list of ETA</td>
<td>Via email to be able to get a pilot on arrival</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>1.3</td>
<td>Vessel provides ETA to river pilots 36/24/12/6 hrs in advance</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>ETA is sent by the agent via email or phone 24hrs in advance</td>
<td>This is the second official channel to gather the ETA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When the time is less than 24 hrs agent might report to all authoriti es by phone</td>
</tr>
<tr>
<td>2</td>
<td>Generate the list of vessels with 30 and 40m and above in beam</td>
<td>The ETA of all vessels arriving are collected from different sources and a special list for the big vessels are generated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This list is mainly for the pilots and the other VTS centres to do their planning</td>
</tr>
<tr>
<td>3</td>
<td>Send the list to the pilots and other VTS centres</td>
<td>The ETA list of vessels with a beam of 30 and 40m and above is sent by fax to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This list is mainly for the pilots and the other VTS centres to do</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>Prepare the plan of arriving departing and passing vessels for the next tide</td>
<td>Mainly Cuxhaven VTS plans for the arriving vessels, Brunsbüttel for the passing and Hamburg for the departing vessels.</td>
</tr>
<tr>
<td>5</td>
<td>Is the vessel tide dependent?</td>
<td>Cuxhaven VTS is responsible for the planning of tide dependent arriving vessels</td>
</tr>
<tr>
<td>5.1</td>
<td>Check the next tide window and the water level prognoses</td>
<td></td>
</tr>
<tr>
<td>5.1.1</td>
<td>Is the water level expected to increase sufficiently?</td>
<td>All VTS centres have to confirm an increasing tendency in the water</td>
</tr>
<tr>
<td></td>
<td>level gauges</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>Is the berth free?</td>
<td>Big container vessels have guaranteed berth within a specific time and tide limits. In case any delays occur from incoming and/or outgoing side, it is necessary to check it again.</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Vessel enters</td>
<td>If yes, go to 5.2.1, if no go to 5.2.2.</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Wait outside for a free berth and the next tide</td>
<td>When the berth is not free the tide dependent vessel will miss the tide window.</td>
</tr>
<tr>
<td>6</td>
<td>Is there any vessel ready to depart?</td>
<td>Although the plans are made in advance for arrival and departure, due to last minute changes</td>
</tr>
</tbody>
</table>

If yes, go to 6.1, if no, go to 6.2.
and considering the time to navigate the river for an incoming vessel, it might occur that another vessel announce her departure after the incoming vessel entered.

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Is the added beam ( \geq 90 \text{m} )?</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6.1.1</td>
<td>Is the meeting position of 2 vessels above Stör?</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>6.1.2</td>
<td>Avoid encountering in the restricted area</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1.3</td>
<td>Advise the vessel to adjust speed and arrange them meet outside the restricted area</td>
<td>1</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

If yes, go to 6.1.1, if no, go to 6.2.
If yes, go to 6.1.2, if no, go to 6.2.
Process ends.
6.2 Vessel enters, and the passage is monitored

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>Process ends.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key to table**

1 = responsible
2 = participating
3 = to be informed

**Table 5: Incoming traffic process description with more information**

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**Standard Process Description – Outgoing traffic**

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
<th>Function</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Send ETD 2 hrs before departure - 4 hrs before departure for the</td>
<td>2 1 2 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hamburg VTS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brunsbüttel VTS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cuxhaven VTS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vessel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terminals</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pilots</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>Send ETDs to Port VTS via computer</td>
<td>When harbour pilots enter the ETDs of the vessels on their computers they can be seen by the Port VTS Centre</td>
<td>3</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>For the big vessels calculate the time of passing Finkenwerder and fax this information to VTS Brunsbüttel</td>
<td>When the vessel is not tide-dependent the standard planning procedure is that the passing time of Finkenwerder of the departing vessel is given to the incoming vessel as passing time of E1 buoy</td>
<td>1</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>Can the vessel depart?</td>
<td>Two questions to be asked at this point to</td>
<td>2</td>
</tr>
<tr>
<td>4.1</td>
<td>Is there an incoming vessel in the river already?</td>
<td>Although the plans are made in advance for arrival and departure, due to last minute changes and considering the time to navigate the river for an incoming vessel, it might occur that another vessel announce her departue after the incoming vessel entered.</td>
<td>3</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Is the added beam $\geq$ 90m</td>
<td>The beams of 2 encountering vessels</td>
<td>1</td>
</tr>
</tbody>
</table>
### Process Description

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Actions</th>
<th>Values</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.2</td>
<td>Is the meeting position above the Stör?</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Above the Stör river is restricted for encountering of vessels with an added beam &gt;= 90m (see process 4.1.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1.3</td>
<td>Avoid encountering within the restricted area</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>It is done via the process 4.1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1.4</td>
<td>Advise the vessel to adjust speed and arrange them to meet outside the restricted area</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

---

- Added simply together and if the result is >= 90m, there are restrictions for encountering.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>Is the vessel tide dependent?</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>If yes, go to 4.2.1, if no, go to 4.2.2</td>
</tr>
<tr>
<td>4.2.1</td>
<td>All sectors check the water level gauges</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Whether the water level is increasing or not is to be asked at the process 6</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Provide the given Finkenwerder passage time of the outgoing vessel as the entrance time of incoming vessel of any size (Time of passing Elbe 1 buoy)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Vessel departs, and it is monitored.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Is water level increasing in all areas?</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>If yes, go to 6.1, if no go to 6.2.1/6.2.2/6.2.3</td>
</tr>
<tr>
<td></td>
<td>Process Description</td>
<td>Schulau is the point where the vessels need to pass at the high water due to insufficient depth there.</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>---</td>
<td>---------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6.1</td>
<td>Calculate the earliest and latest passage time of Schulau</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2</td>
<td>Can the vessel discharge ballast?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2.1</td>
<td>Can the vessel cut and go earlier?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2.2</td>
<td>Can the vessel remove some cargo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2.3</td>
<td>Do not allow departure / Wait for the next tide</td>
<td>Enter means the passing time of E1 buoy for the incoming vessel</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Let any incoming vessel enter 1hr/1hr 15m later than the passage time Finkenwerder of the</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

136
### Table 6: Outgoing traffic process description with more information

<table>
<thead>
<tr>
<th>outgoing vessel</th>
<th>1</th>
<th>2</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>9</strong> Ensure meeting of vessels including added beam of more than 90m to take place in front of Brunsbüttel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>10</strong> Is it possible?</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>If yes, go to 5, if no go to 4.1.3</th>
</tr>
</thead>
</table>

**Key to table**

1 = responsible  
2 = participating  
3 = to be informed
References


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Kitzinger, J., 1994. The methodology of Focus Groups: the importance of interaction between research participants. Sociology of Health & Illness, January, pp. 103-121.


